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A GUIDE TO THE SELECTION OF COST-EFFECTIVE WASTEWATER TREATMENT SYSTEMS

BECHTEL, INCORPORATED

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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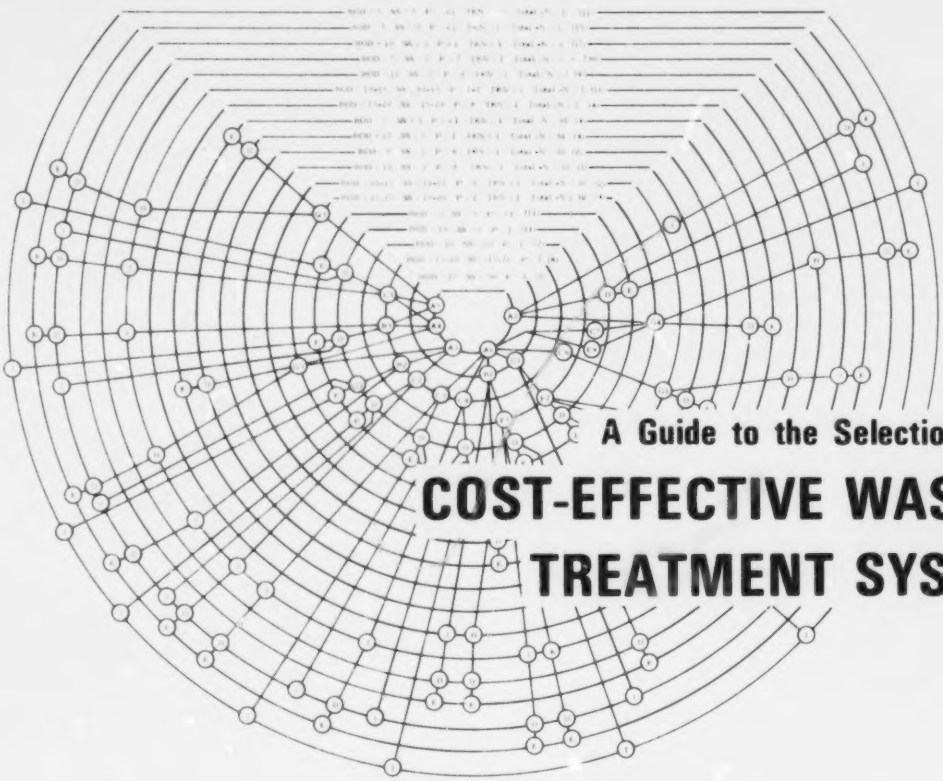

A Guide to the Selection of

COST-EFFECTIVE WASTEWATER TREATMENT SYSTEMS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
Washington, D. C. 20460

231

EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

NOTE

Methods of estimating costs and evaluating the cost-effectiveness of land-application systems are being developed in a separate document, entitled, Technical Report, Costs of Wastewater Treatment by Land Application, No. EPA 430/9-75-003, which will become available later in 1975.

EPA-430/9-75-002
July 1975

A GUIDE TO THE SELECTION OF COST-EFFECTIVE WASTEWATER TREATMENT SYSTEMS

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U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

FOREWORD

U.S. Environmental Protection Agency
Office of Water Program Operations

TECHNICAL REPORT

A GUIDE TO THE SELECTION OF COST-EFFECTIVE WASTEWATER TREATMENT SYSTEMS

In response to the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) this country has undertaken an unprecedented building program for new and improved wastewater treatment works. It is incumbent upon the EPA and all other government entities to ensure that the funds authorized for this enormous undertaking be justifiably expended. Accordingly the Act requires that all construction grant applicants perform a cost-effective analysis to determine the most cost-effective wastewater management alternative.

Publication of the Cost-Effectiveness Analysis Guidelines (APPENDIX C of the Report) set forth the procedures for making a cost-effective analysis. This Technical Report provides technical information including wastewater treatment costs and examples of how to use the cost data in performing a cost-effective analysis to further assist the construction grant applicant. It is emphasized that the Report presents information only and does not contain mandatory requirements. The data provides a guide for planners, engineers and decision makers at all levels of government to evaluate the cost-effectiveness of alternative wastewater treatment methods.

This publication is not intended as a design manual but as an effective means for making preliminary cost comparisons of wastewater treatment alternatives based upon the assumptions set forth in the Report. These assumptions may not be valid in certain cases thus limiting the Report's applicability.

It is the intention of the Environmental Protection Agency to revise and update this Technical Report as more technical information becomes available. The most valuable source of information for revisions will be the actual experiences of those using the Report. All users are encouraged to submit such information to the Director of the Municipal Construction Division (WH-447), Office of Water Program Operations, Environmental Protection Agency, Washington, D. C. 20460.

for John T. Rhett
James L. Agee
Assistant Administrator
for Water and Hazardous Materials

Abstract

Flow sheets describing various unit processes associated with wastewater treatment and sludge handling are presented. Curves depicting total, O & M and amortized capital cost in cents per thousand gallons influent wastewater are shown for plant capacities ranging from 1-100 MGD. The unit processes described, for which cost data were developed, include conventional and advanced wastewater treatment units as well as most sludge handling and processing units. Diagrams are presented which show logical combinations of the unit processes to form complete wastewater treatment systems capable of achieving various levels of effluent quality.

From these diagrams, alternative wastewater treatment systems capable of achieving the same effluent quality can be selected, and costs of the systems can be determined by referring to the unit process cost curves.

The data provide a guide for planners, engineers, and decision makers at all levels of government to evaluate cost-effectiveness of alternative wastewater treatment proposals.

Appendices have been prepared to enable the users of this guide to obtain cost-effective information when assumptions other than those used here prevail. In Appendix A, word descriptions of various unit processes associated with wastewater treatment and sludge handling are presented. In Appendix B, equations depicting capital, fixed O&M and flow variable O&M costs in cents per thousand gallons influent wastewater are shown for plant capacities ranging from 1 to 100 MGD. From these equations, the cost of a wastewater treatment system can be determined by summing costs associated with each unit process in the treatment system.

This report was originally submitted in fulfillment of Contract Number 68-01-0973, and is now resubmitted revised by Order Number 68-01-1276 under the sponsorship of the U.S. Environmental Protection Agency.

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CONTENTS

Section Page

Foreword ii
Abstract iii

I INTRODUCTION

Purpose I-1
Definition I-1
Application I-2
Limitations I-3

II UNIT WASTEWATER TREATMENT PROCESSES

Unit Processes II-1
Unit Process Flow Sheets II-2

III COSTS OF UNIT PROCESSES

Cost Determinations III-1
Costs Included III-2
Costs Not Included III-3
Cost Curves for Unit Processes III-3
Factors Other Than Cost Considered in Selecting Wastewater Treatment Unit Processes III-4

Calculation of Capital, O&M Cost, and Total Costs III-5

IV COMBINING UNIT PROCESSES FOR VIABLE WASTEWATER TREATMENT SYSTEMS

Definition IV-1
Combined Unit Process Diagrams IV-1

V DETERMINING COST EFFECTIVENESS OF WASTEWATER TREATMENT SYSTEMS

Procedure for Use of Diagrams and Comparaing Alternative Systems Costs V-1

Examples of Comparing Cost-Effectiveness of Complete Wastewater Treatment Systems V-4

APPENDIX A Unit Process Descriptions
APPENDIX B Cost Formulae
APPENDIX C Cost-Effectiveness Analysis Guidelines

ABBREVIATIONS AND BIBLIOGRAPHY

TABLES, FLOW SHEETS, DIAGRAMS

Section		No.	Page
II	Alternative Methods and Equipment for Various Processes	II-1	II-5
	Unit Process Flow Sheets		II-6
III	Properties and Cost of Common Waste Treatment Chemicals and Costs of Energy	III-1	III-5
	Factors Other than Cost Normally Considered in Selection of Wastewater Treatment and Sludge Handling Unit Processes	III-2	III-7
	Unit Process Cost Curves		III-6
IV	Combined Unit Processes for Wastewater Treatment Systems	IV-1	IV-4
	Combined Unit Processes for Sludge Handling Systems	IV-2	IV-5
V	Example No. 1	V-1	V-7
	Example No. 2	V-2	V-11
	Example No. 3	V-3	V-12
Appendix B	Flow-Variable Cost Elements	B-1	B-5

A GUIDE TO THE SELECTION OF COST-EFFECTIVE WASTEWATER TREATMENT SYSTEMS

Section I - Introduction

1.1 Purpose

The application of cost-effective methodologies is needed for the development of sound waste treatment management systems responsive to the Federal Water Pollution Control Act Amendments of 1972 (the Act). This technical report represents an initial effort to aid in the identification of most of the wastewater treatment process sequences (other than land treatment and pond systems) currently available to meet point source discharge standards. In addition to identifying a wide range of treatment alternatives available to meet the standards, this technical report is intended to aid in the further screening of alternatives as to their cost-effective potential.

1.2 Definition

For waste treatment management systems, a cost-effective solution is one which will minimize total resources costs to the nation over time to meet the Federal and State water quality standards and treatment requirements. Resources costs include capital (construction and lands); operation, maintenance and replacements; and social and environmental costs.

In comparing joint municipal-industrial waste treatment management systems to separate systems, a cost-effective system is one in which the total resources cost over time are less than the total resources costs of other alternative systems.

A cost-effective waste treatment management system may provide for wastewater reuse when the sale or net value from wastewater reuse will, at a minimum, offset any additional resources cost to the system which is required to meet Federal and State water quality standards and treatment requirements.

1.3 Application

This publication is intended to aid water quality management planners, decision makers at all levels of government, and design engineers in evaluating cost-effective potential of alternative wastewater treatment systems. This publication is not intended as a design manual but as an effective means for making preliminary cost comparisons based upon the assumptions set forth in this report. The cost-effectiveness data presented should be of particular value throughout the planning, project formulation, and preliminary engineering process.

It is expected that the cost effectiveness data presented in the report will be revised and updated periodically. This is a necessity since waste treatment costs are continually changing, and new and improved waste treatment techniques and methodologies are rapidly appearing. As more experience is gained in practice with the newer advanced wastewater treatment and sludge handling processes, more cost data will become available for analysis. Also, improvements in processes already in current use will most likely result in significant cost changes.

1.4 Limitations

Although the information presented should be of particular value throughout the planning, project formulation, and preliminary engineering process, the reader should be aware of the limitations of this publication. He should realize that the circumstances of a particular situation may alter the cost-effectiveness data presented. For example, the influence of very cold weather would likely eliminate from consideration a highly temperature dependent process such as ammonia stripping and could change costs for other systems such as activated sludge and trickling filters. Similarly, if the percentage of industrial wastewater or inflow and infiltration is high or if the composition of the waste stream differs markedly from the "typical" influent wastewater quality assumed herein, modifications must be made in choosing cost-effective systems. Similar adjustments would have to be made if any of the design criteria as shown on the process flow sheets were to be changed.

Additionally, the reader should be aware that not every wastewater treatment method and piece of equipment is presented. Alternatives to the processes considered are presented in Table II-1.

Section II - Unit Wastewater Treatment Processes

2.1 Unit Processes

There are two basic areas of concern in wastewater treatment. One is the removal of deleterious matter from wastewater: suspended solids, BOD, bacteria, phosphorous and nitrogen. The other is handling a variety of sludges generated within the wastewater treatment systems. Unit processes presently available for wastewater treatment and sludge handling are presented at the end of this chapter in the form of flow sheets.

Before developing costs associated with each unit process or making cost-effective analyses, it was first necessary to evaluate relative treatment efficiencies of the various unit processes and all combinations thereof. The first step required in this evaluation was the selection of representative influent wastewater characteristics. Based upon these characteristics and estimated treatment efficiencies, effluent characteristics for each unit process were determined. Nominal design criteria, equipment sizing and quantities and characteristics of sludges generated from the various processes were then established.

To determine effluent quality expected from each unit process, a "typical" raw influent wastewater quality was chosen, as described below:

Biochemical Oxygen Demand, 5 days @ 20° C	210 mg/l
Total Suspended Solids	230 mg/l
Total Phosphorus (total as P)	11 mg/l
TKN (as N)	30 mg/l
Total - N (as N)	30 mg/l
pH	7.3
Alkalinity (as $CaCO_3$)	300 mg/l

The raw influent wastewater quality listed above is intended to represent a rough average of a wide variety of wastewater qualities found in the United States. The raw influent quality and process efficiencies chosen were determined from available literature listed in the bibliography. Design parameters for equipment associated with each unit process were determined also from available literature, including guidelines listed in the "Ten States Stanards" and from recent engineering experience. They represent commonly accepted values. From the selected design parameters and loadings on the processes, the units were sized based on influent wastewater flow. The quantities of sludges generated by the unit processes were calculated and sludge handling units' sizes were based upon the sludge quantities, characteristics, and selected design parameters.

2.2 Unit Process Flow Sheets

All major equipment associated with each unit process are depicted on the unit process flow sheets. Other equipment and appurtenances generally associated with each unit process are included in the cost equations described in the addendum even though not shown on the flow sheets.

Influent quality, effluent quality, design larameters, unit sizing and, where appropriate, sludge quantities produced by the unit process are depicted on the flow sheets. Also shown on the flow sheets, where applicable, are chemical quantities used, air requirements and waste gases produced. Other quality parameters are presented where necessary for specific unit process characterization.

Table II-1 lists the process methods and basic equipment upon which cost data are based. The Table also lists alternative methods and/or equipment that could be used in place of those selected.

Certain unit processes are designed to remove specific pollutants: suspended solids, BOD, phosphorus, or nitrogen compounds. In the course of removing the primary pollutants for which the unit process is intended, other deleterious materials are partially removed as well. For example, unit processes comprising chemical treatment are designed primarily to remove phosphorus, but these steps are also effective in removing suspended solids and a relatively high percentage of BOD. A system comprising addition of chemicals (lime, alum or ferric chloride) in the primary sedimentation process to effect phosphorus removal would produce an effluent of lower BOD content than would conventional primary sedimentation. Because of the differences in BOD content of the effluent from primary treatment in the two systems, design parameters of secondary treatment would change accordingly, even if the same secondary treatment process was used in both cases.

Therefore, design parameters and all characteristics of a given unit operation will vary depending upon the primary purpose [illegible] it process in the system, the unit processes preceding in the system and, i[illegible]ew cases, following in the system. For this reason, in most cases there are a number of flow sheets for a given unit process. For example, there are five flow sheets for the primary sedimentation process and eight flow sheets for the activated sludge process. In the sludge handling unit processes, there are nine flow sheets for the sludge dewatering process and seven flow sheets for sludge incineration. Each flow sheet is specific to a given condition and may be identified by the following:

- The title of each flow sheet identifies the unit process and the function of the process in the system.
- For liquid treatment unit processes, the sources of influents that can be treated in the particular flow sheet are listed.
- For sludge handling unit processes, the sources of sludges that can be handled in the particular flow sheet are listed.

By these means, compatible unit processes can be selected and used as building blocks to form complete systems.

TABLE II-1

ALTERNATIVE METHODS AND EQUIPMENT FOR VARIOUS PROCESSES

Process	Methods and Equipment Selected	Alternative Methods & Equipment
Sedimentation	Circular Units	Rectangular Units
Thickening	Gravity	Flotation
Secondary Treatment	Trickling Filters Activated Sludge	Rotary Biological Filters
Aeration	Air (Media) Diffusers (Method)	Oxygen Mechanical Brushes
Filtration	Dual-Media	Microscreens Multi-media Single-media
Carbon Adsorption	Granular	Powdered
Digestion	Anaerobic	Aerobic
Sludge Stabilization	Digestion Heat Treatment	Chemical-Chlorine; Lime
Dewatering	Air Drying Vacuum Filters	Sludge Lagoons Centrifuges Pressure Filters
Incineration	Multiple-Hearth	Fluid-Bed Rotary Kiln
Recalcination	Multiple-Hearth	Fluid-Bed Rotary Kiln
Disinfection	Chlorination	Ozonation
Chemical Treatment (Primary & Tertiary)	Flocculation-Clarifiers	Separate Flocculation & Clarification Units
Biological Nitrification	Separate suspended growth Aeration Basin	Combined with Activated Sludge Basin or separate basin with fixed growth
Biological Denitrification	Separate basin with suspended growth	Separate basin with Fixed growth or combined with nitrification
Ion Exchange and regeneration	Ammonia Stripping Tower, to remove NH_3-N from regenerant	Electrolysis with Break Point Chlorination to remove NH_3-N from regenerant
Preliminary Treatment Grit Removal	Gravity Grit Chamber	Aerated Grit Chamber Cyclone Separation
Screening	Bar Racks	Comminutors
Flow Measurement	Parshall Flume	Palmer-Bowlus Flume

WASTEWATER TREATMENT PROCESSES
FLOW SHEETS

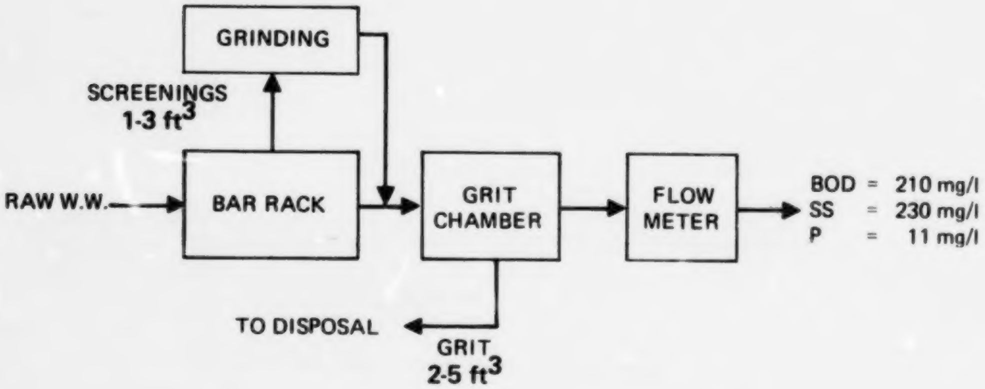
		Page
Preliminary Treatment	AA	II-7
Pumping	AB	II-8
Primary Sedimentation	A-1 thru A-5	II-9 thru II-13
Trickling Filter	B-1 thru B-3	II-14 thru II-16
Activated Sludge	C-1 thru C-8	II-17 thru II-24
Filtration	D	II-25
Activated Carbon	E	II-26
Two Stage Tertiary Lime	F-1 thru F-2	II-27 thru II-28
Biological Nitrification	G-1 thru G-4	II-29 thru II-32
Biological Denitrification	H	II-33
Ion Exchange	I	II-34
Breakpoint Chlorination	J	II-35
Ammonia Stripping	K	II-36
Disinfection	R	II-37

SLUDGE HANDLING PROCESSES
FLOW SHEETS

Anaerobic Digestion	L-1 & L-2	II-38 thru II-39
Heat Treatment	M-1 & M-2	II-40 thru II-41
Air Drying	N-1 & N-2	II-42 thru II-43
Dewatering	O-1 thru O-9	II-44 thru II-52
Incineration	P-1 thru P-7	II-53 thru II-59
Recalcination	Q-1 thru Q-3	II-60 thru II-62

AA. PRELIMINARY TREATMENT

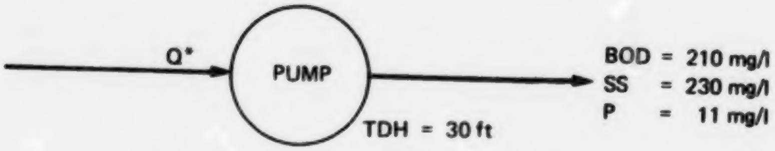
Influent: Raw Wastewater


GRINDING
SCREENINGS
1-3 ft³
RAW W.W.
BAR RACK
GRIT CHAMBER
FLOW METER
BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l
TO DISPOSAL
GRIT
2-5 ft³

Design criteria in bold type are per mgd influent wastewater flow.

AB. RAW WASTEWATER PUMPING

Influent: Effluent from Preliminary Treatment AA

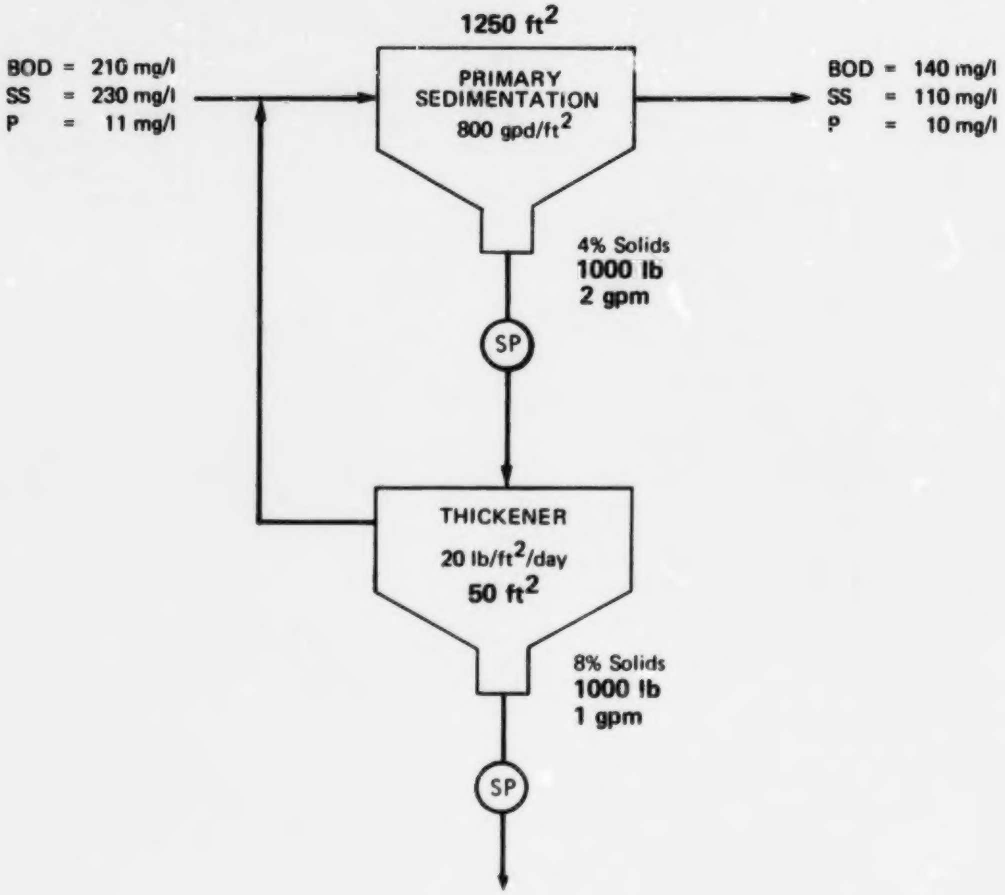

Q*
PUMP
TDH = 30 ft
BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l

*Peak Capacity (with largest unit out of service) = 2 x Q

Design criteria in bold type are per
mgd influent wastewater flow.

A-1. PRIMARY SEDIMENTATION – CONVENTIONAL

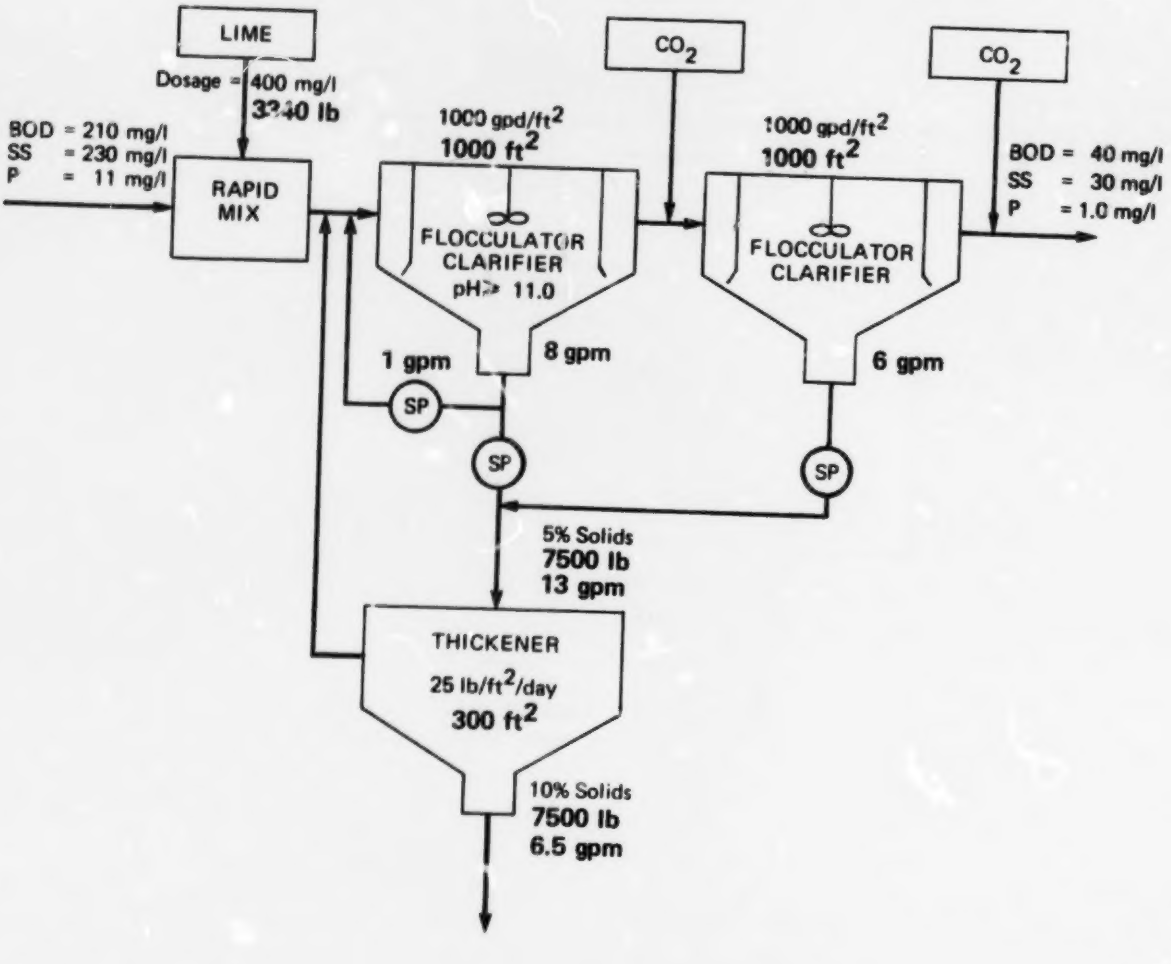
Influent: **Effluent from Preliminary Treatment AA or**
Raw Wastewater Pumping AB


1250 ft²
BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l
PRIMARY SEDIMENTATION
800 gpd/ft²
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
4% Solids
1000 lb
2 gpm
SP
THICKENER
20 lb/ft²/day
50 ft²
8% Solids
1000 lb
1 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

A-2. PRIMARY SEDIMENTATION – TWO-STAGE LIME ADDITION

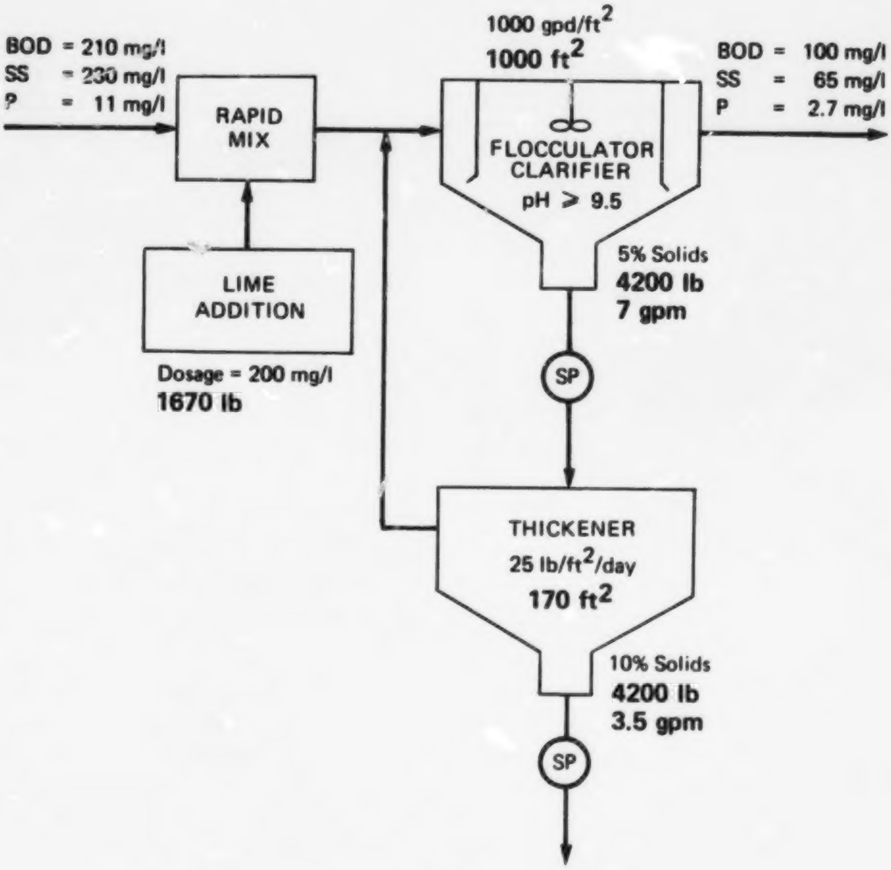
Influent: **Effluent from Preliminary Treatment AA or**
Raw Wastewater Pumping AB


LIME
Dosage = 400 mg/l
3340 lb
BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l
RAPID MIX
1000 gpd/ft²
1000 ft²
FLOCCULATOR CLARIFIER
pH ≥ 11.0
CO_2
1000 gpd/ft²
1000 ft²
FLOCCULATOR CLARIFIER
CO_2
BOD = 40 mg/l
SS = 30 mg/l
P = 1.0 mg/l
1 gpm
8 gpm
6 gpm
SP
SP
SP
5% Solids
7500 lb
13 gpm
THICKENER
25 lb/ft²/day
300 ft²
10% Solids
7500 lb
6.5 gpm

Design criteria in bold type are per mgd influent wastewater flow.

A-3. PRIMARY SEDIMENTATION – SINGLE-STAGE LIME ADDITION

Influent: **Effluent from Preliminary Treatment AA or**
Raw Wastewater Pumping AB

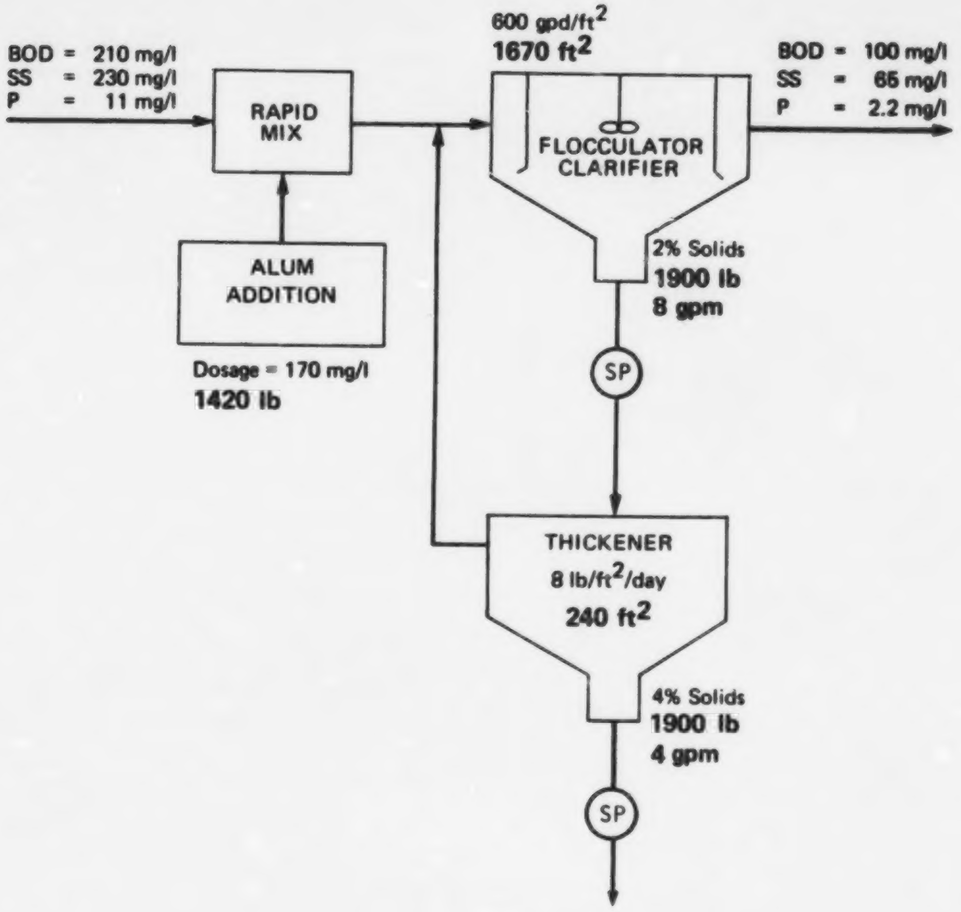


BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l
RAPID MIX
LIME ADDITION
Dosage = 200 mg/l
1670 lb
1000 gpd/ft2
1000 ft2
FLOCCULATOR CLARIFIER
pH ≥ 9.5
BOD = 100 mg/l
SS = 65 mg/l
P = 2.7 mg/l
5% Solids
4200 lb
7 gpm
SP
THICKENER
25 lb/ft2/day
170 ft2
10% Solids
4200 lb
3.5 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

A-4. PRIMARY SEDIMENTATION – ALUM ADDITION

Influent: Effluent from Preliminary Treatment AA or Raw Wastewater Pumping AB

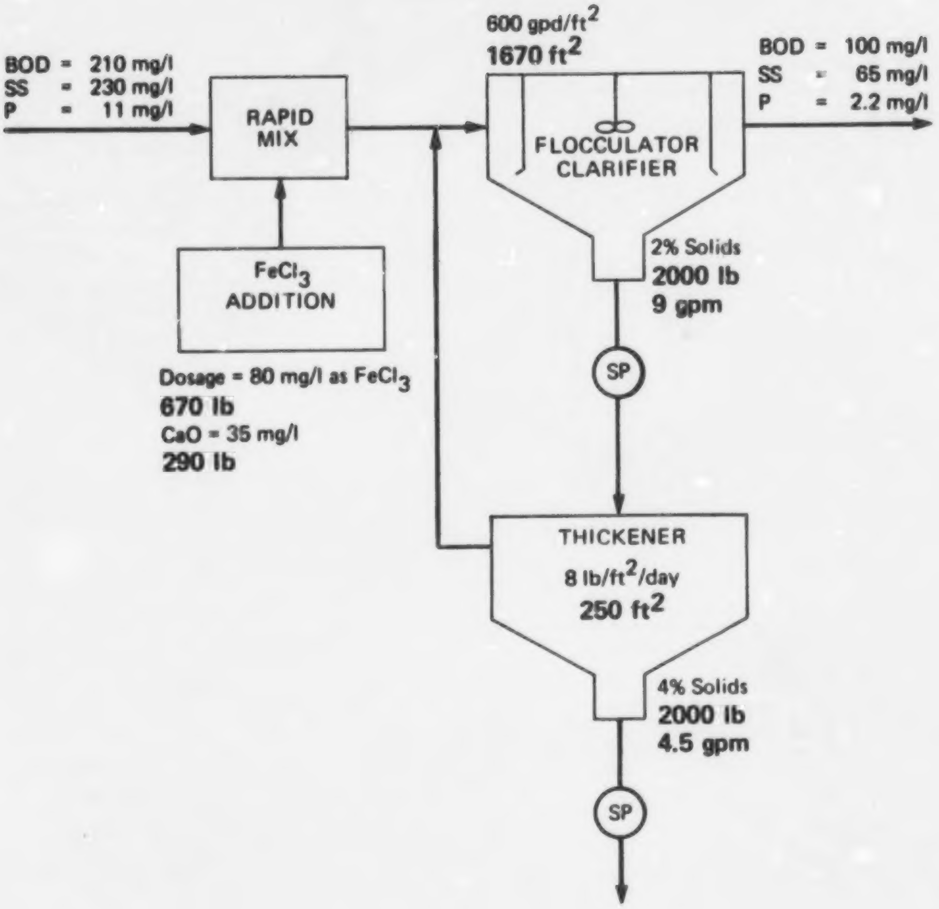


BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l
RAPID MIX
ALUM ADDITION
Dosage = 170 mg/l
1420 lb
600 gpd/ft²
1670 ft²
FLOCCULATOR CLARIFIER
BOD = 100 mg/l
SS = 65 mg/l
P = 2.2 mg/l
2% Solids
1900 lb
8 gpm
SP
THICKENER
8 lb/ft²/day
240 ft²
4% Solids
1900 lb
4 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

A-5. PRIMARY SEDIMENTATION – $FeCl_3$ ADDITION

Influent: Effluent from Preliminary Treatment AA or Raw Wastewater Pumping AB

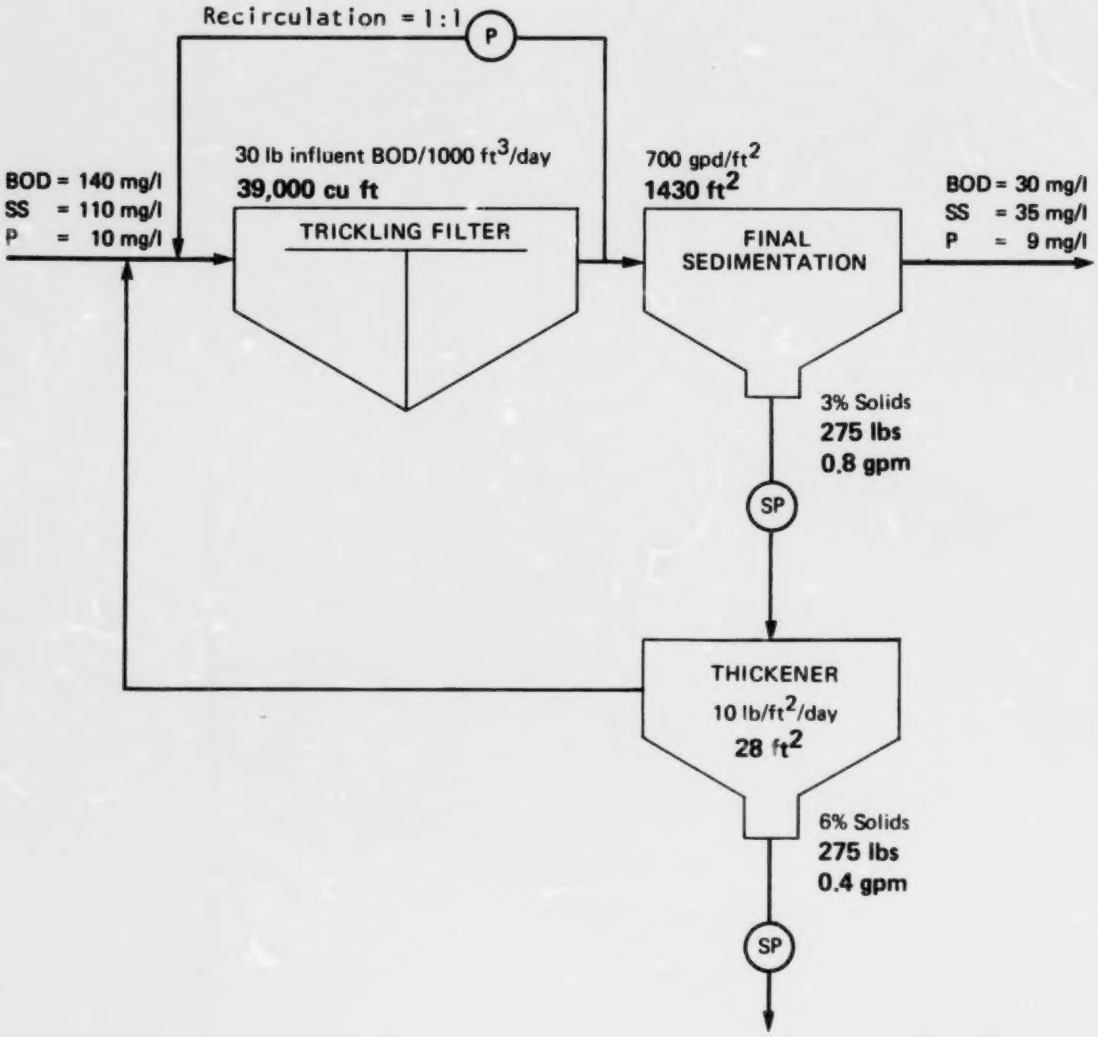


BOD = 210 mg/l
SS = 230 mg/l
P = 11 mg/l
RAPID MIX
$FeCl_3$ ADDITION
Dosage = 80 mg/l as $FeCl_3$
670 lb
CaO = 35 mg/l
290 lb
600 gpd/ft^2
1670 ft^2
FLOCCULATOR CLARIFIER
BOD = 100 mg/l
SS = 65 mg/l
P = 2.2 mg/l
2% Solids
2000 lb
9 gpm
SP
THICKENER
8 lb/ft^2/day
250 ft^2
4% Solids
2000 lb
4.5 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

B-1. TRICKLING FILTER

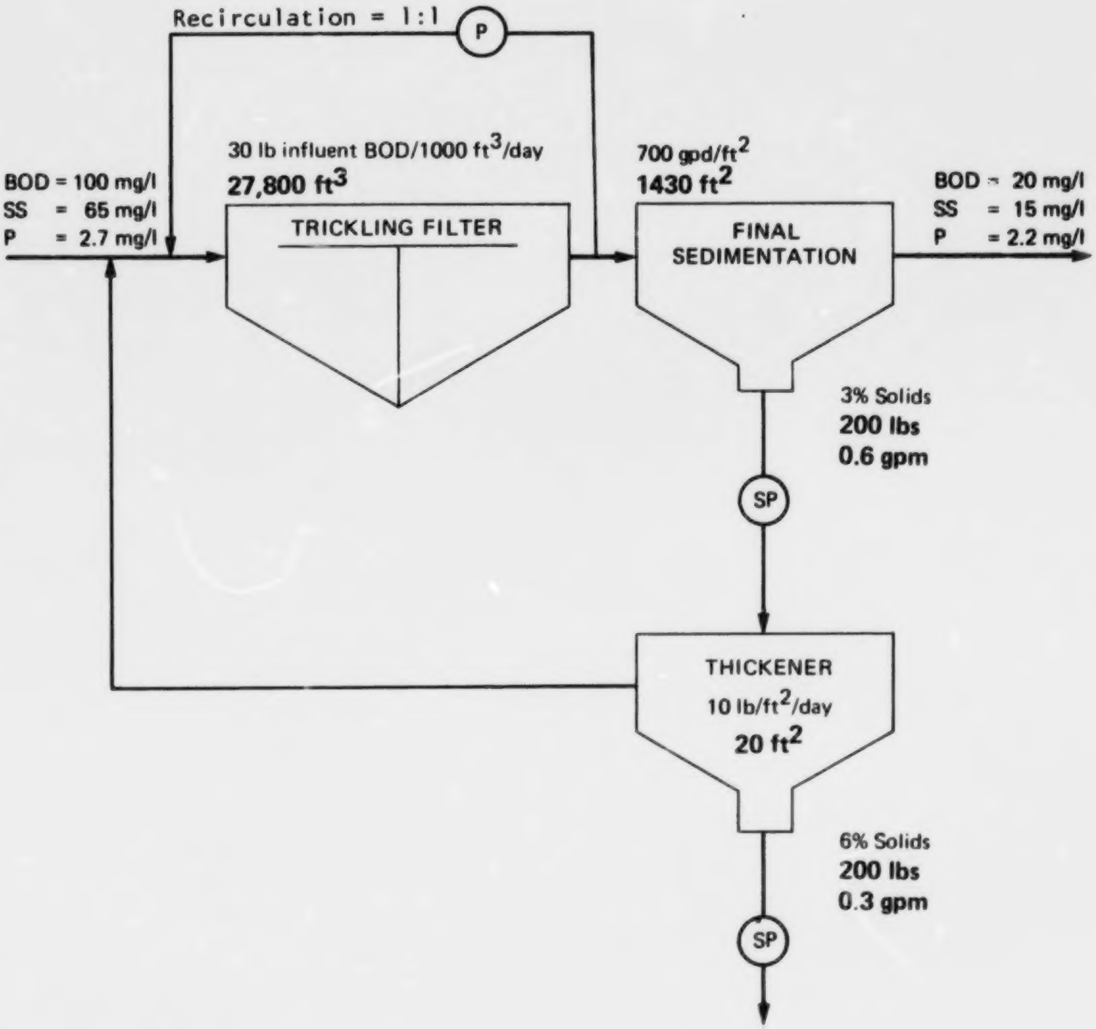
Influent: Effluent From Primary Sedimentation – Conventional A-1


Recirculation = 1:1
P
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
30 lb influent BOD/1000 ft3/day
39,000 cu ft
TRICKLING FILTER
700 gpd/ft2
1430 ft2
FINAL SEDIMENTATION
BOD = 30 mg/l
SS = 35 mg/l
P = 9 mg/l
3% Solids
275 lbs
0.8 gpm
SP
THICKENER
10 lb/ft2/day
28 ft2
6% Solids
275 lbs
0.4 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

B-2. TRICKLING FILTER

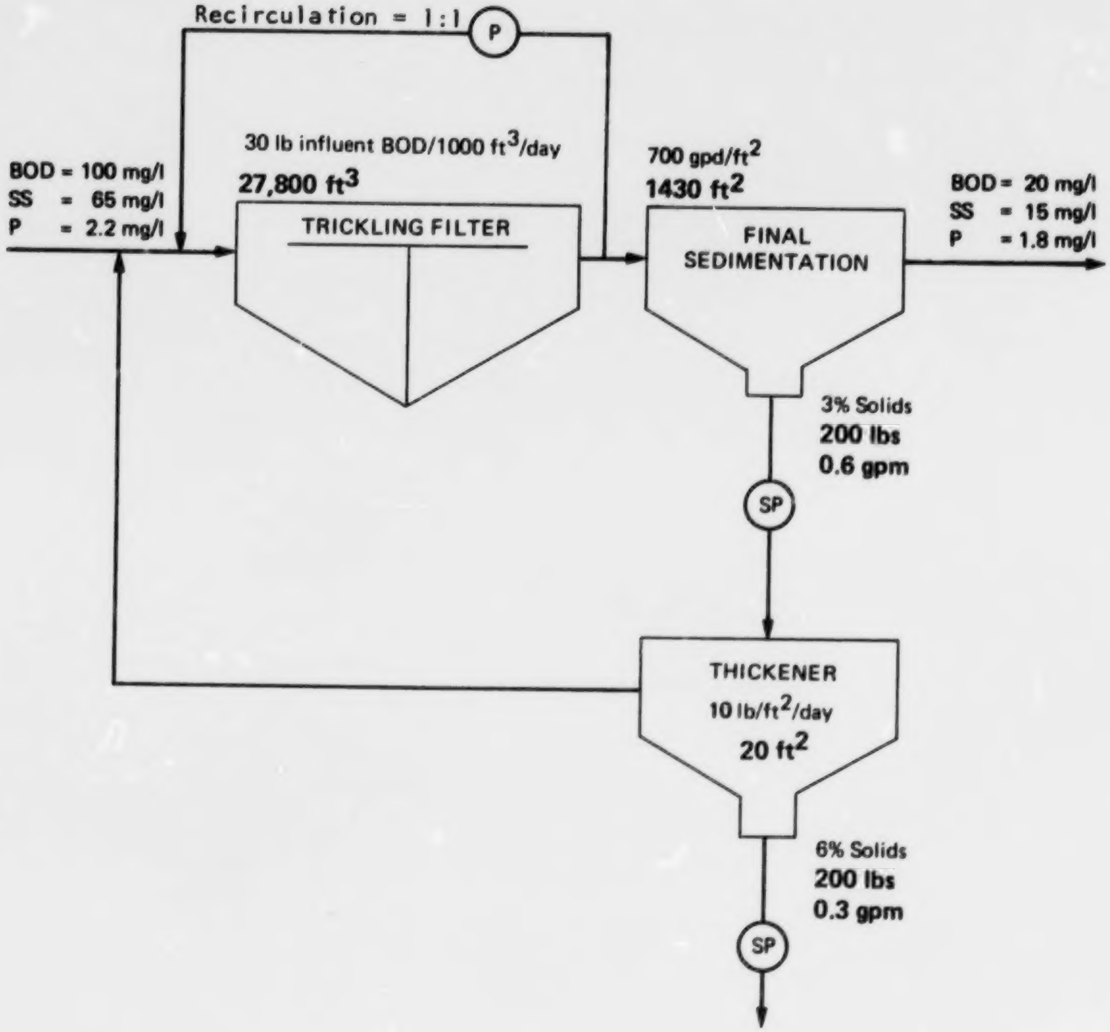
Influent: Effluent From Primary Sedimentation – Single-Stage Lime Addition A-3


Recirculation = 1:1
P
BOD = 100 mg/l
SS = 65 mg/l
P = 2.7 mg/l
30 lb influent BOD/1000 ft³/day
27,800 ft³
TRICKLING FILTER
700 gpd/ft²
1430 ft²
FINAL SEDIMENTATION
BOD = 20 mg/l
SS = 15 mg/l
P = 2.2 mg/l
3% Solids
200 lbs
0.6 gpm
SP
THICKENER
10 lb/ft²/day
20 ft²
6% Solids
200 lbs
0.3 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

B-3. TRICKLING FILTER

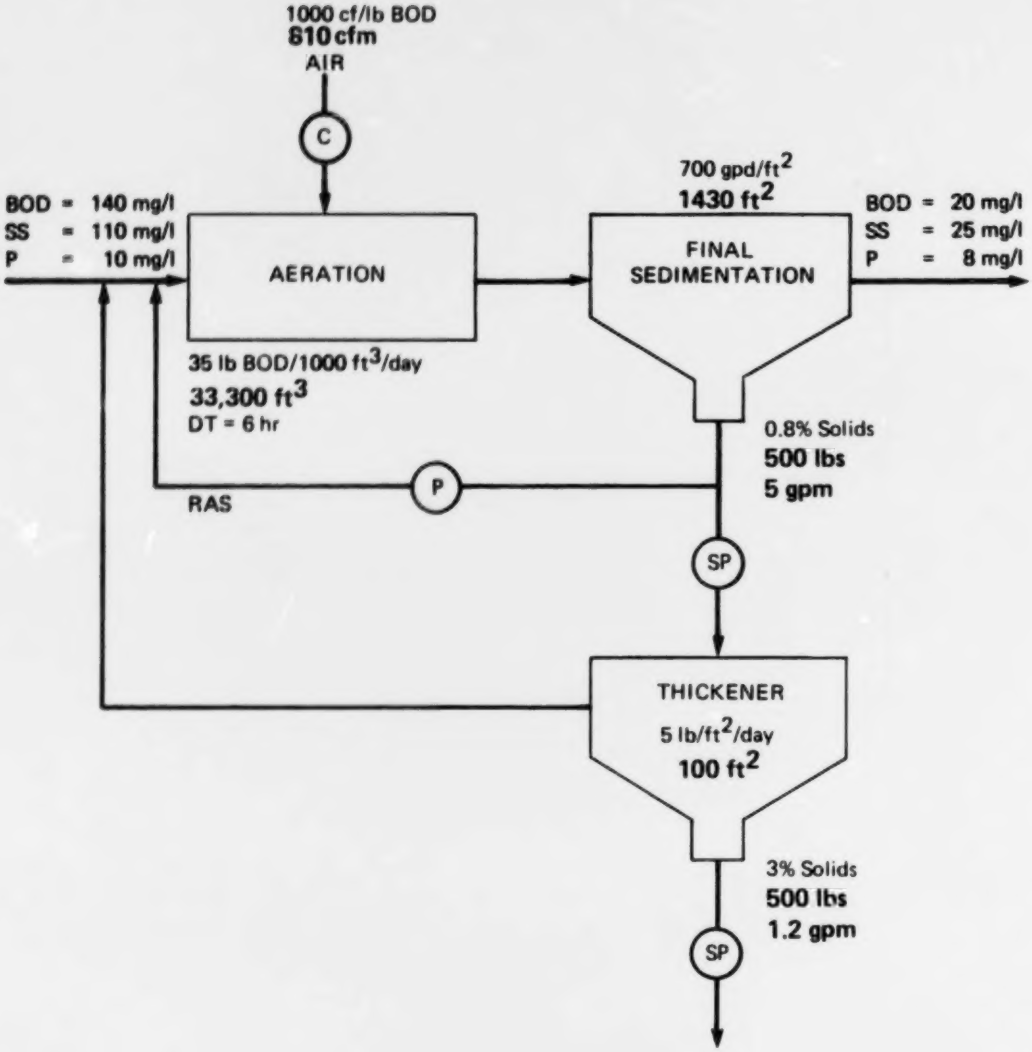
Influent: Effluent From Primary Sedimentation – Alum or $FeCl_3$ Addition A-4 or A-5


Recirculation = 1:1
P
BOD = 100 mg/l
SS = 65 mg/l
P = 2.2 mg/l
30 lb influent BOD/1000 ft³/day
27,800 ft³
TRICKLING FILTER
700 gpd/ft²
1430 ft²
FINAL SEDIMENTATION
BOD = 20 mg/l
SS = 15 mg/l
P = 1.8 mg/l
3% Solids
200 lbs
0.6 gpm
SP
THICKENER
10 lb/ft²/day
20 ft²
6% Solids
200 lbs
0.3 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

C-1. ACTIVATED SLUDGE – CONVENTIONAL

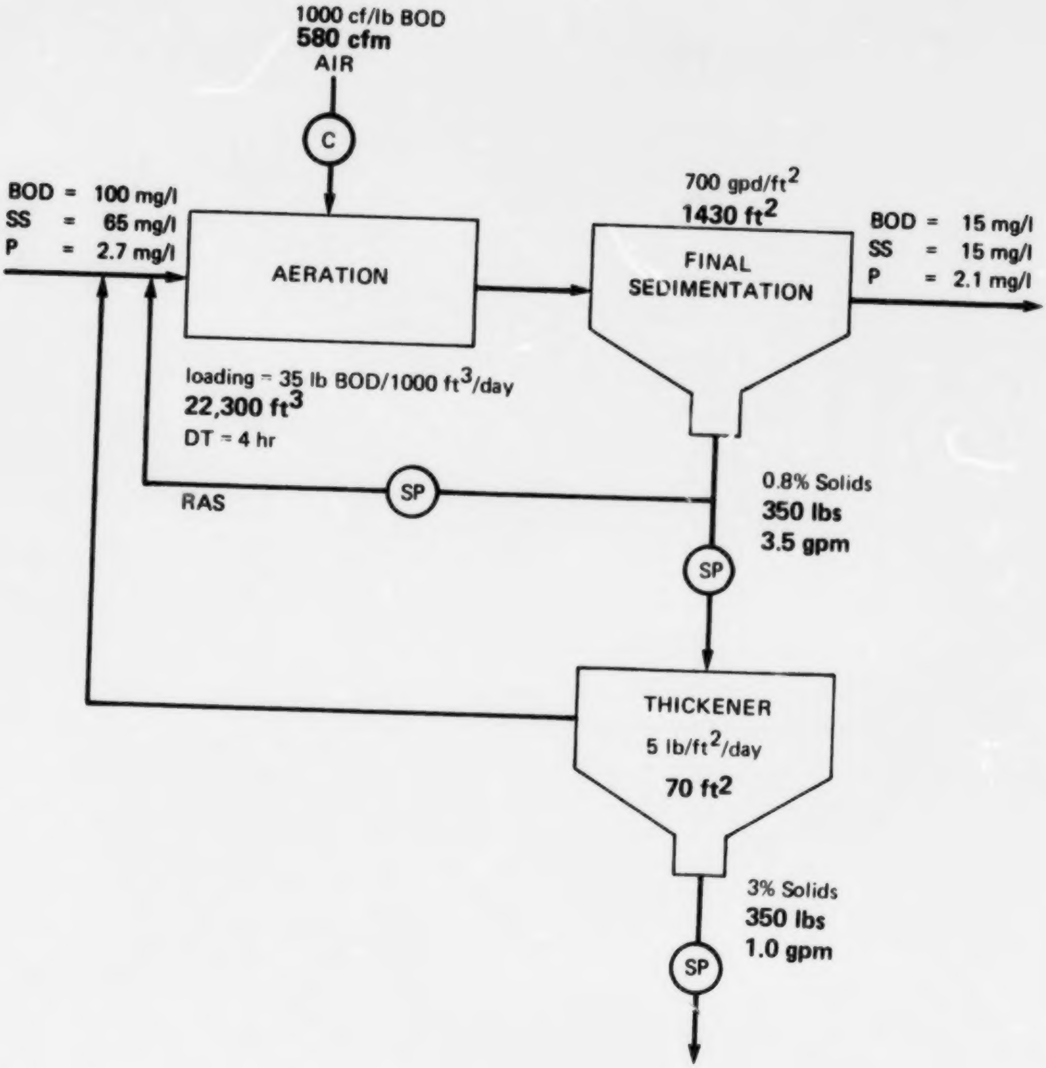
Influent: Effluent from Primary Sedimentation – Conventional A-1


1000 cf/lb BOD
810 cfm
AIR
C
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
AERATION
35 lb BOD/1000 ft³/day
33,300 ft³
DT = 6 hr
700 gpd/ft²
1430 ft²
FINAL SEDIMENTATION
BOD = 20 mg/l
SS = 25 mg/l
P = 8 mg/l
0.8% Solids
500 lbs
5 gpm
P
RAS
SP
THICKENER
5 lb/ft²/day
100 ft²
3% Solids
500 lbs
1.2 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

C-2. ACTIVATED SLUDGE

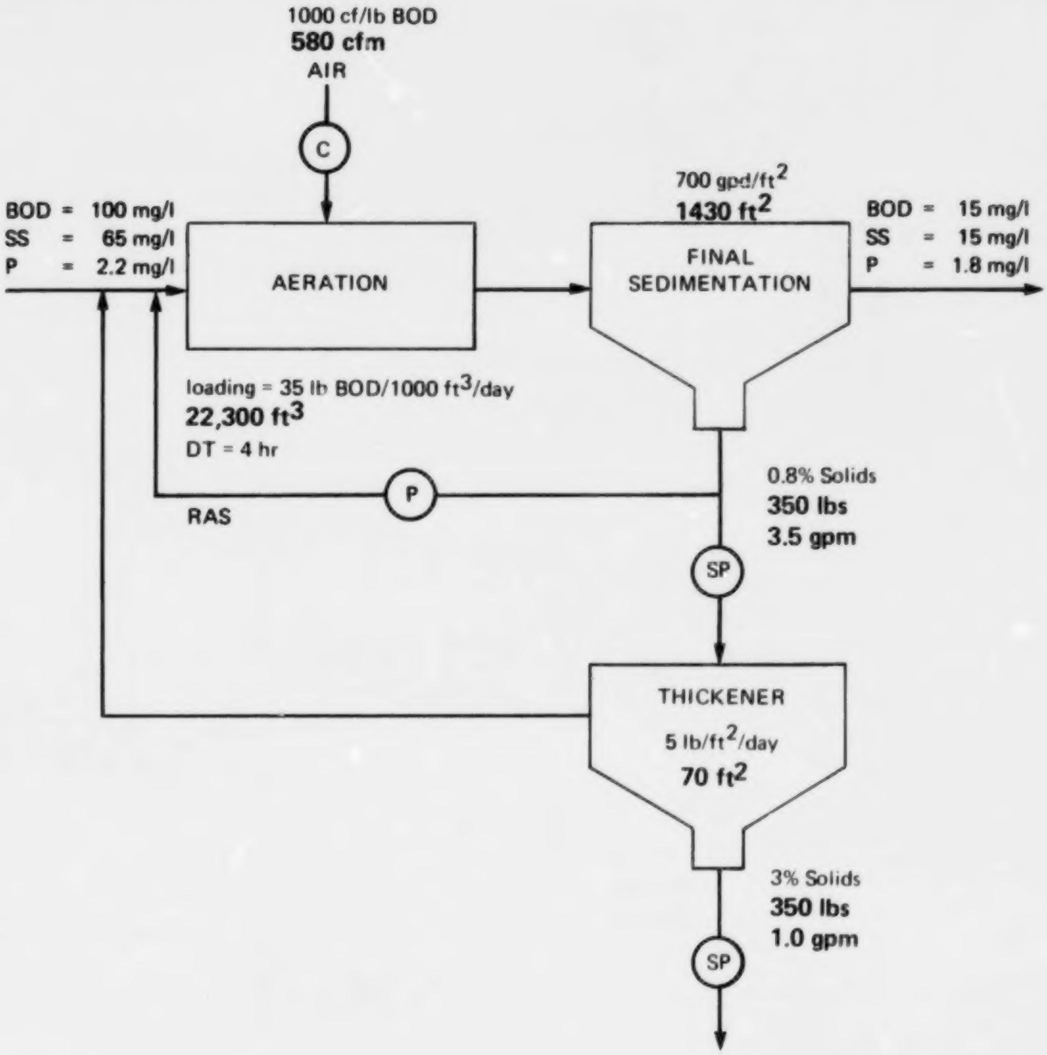
Influent: Effluent from Primary Sedimentation – Single-Stage Lime Addition A-3


1000 cf/lb BOD
580 cfm
AIR
C
BOD = 100 mg/l
SS = 65 mg/l
P = 2.7 mg/l
AERATION
loading = 35 lb BOD/1000 ft3/day
22,300 ft3
DT = 4 hr
700 gpd/ft2
1430 ft2
FINAL SEDIMENTATION
BOD = 15 mg/l
SS = 15 mg/l
P = 2.1 mg/l
RAS
SP
0.8% Solids
350 lbs
3.5 gpm
SP
THICKENER
5 lb/ft2/day
70 ft2
3% Solids
350 lbs
1.0 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

C-3. ACTIVATED SLUDGE

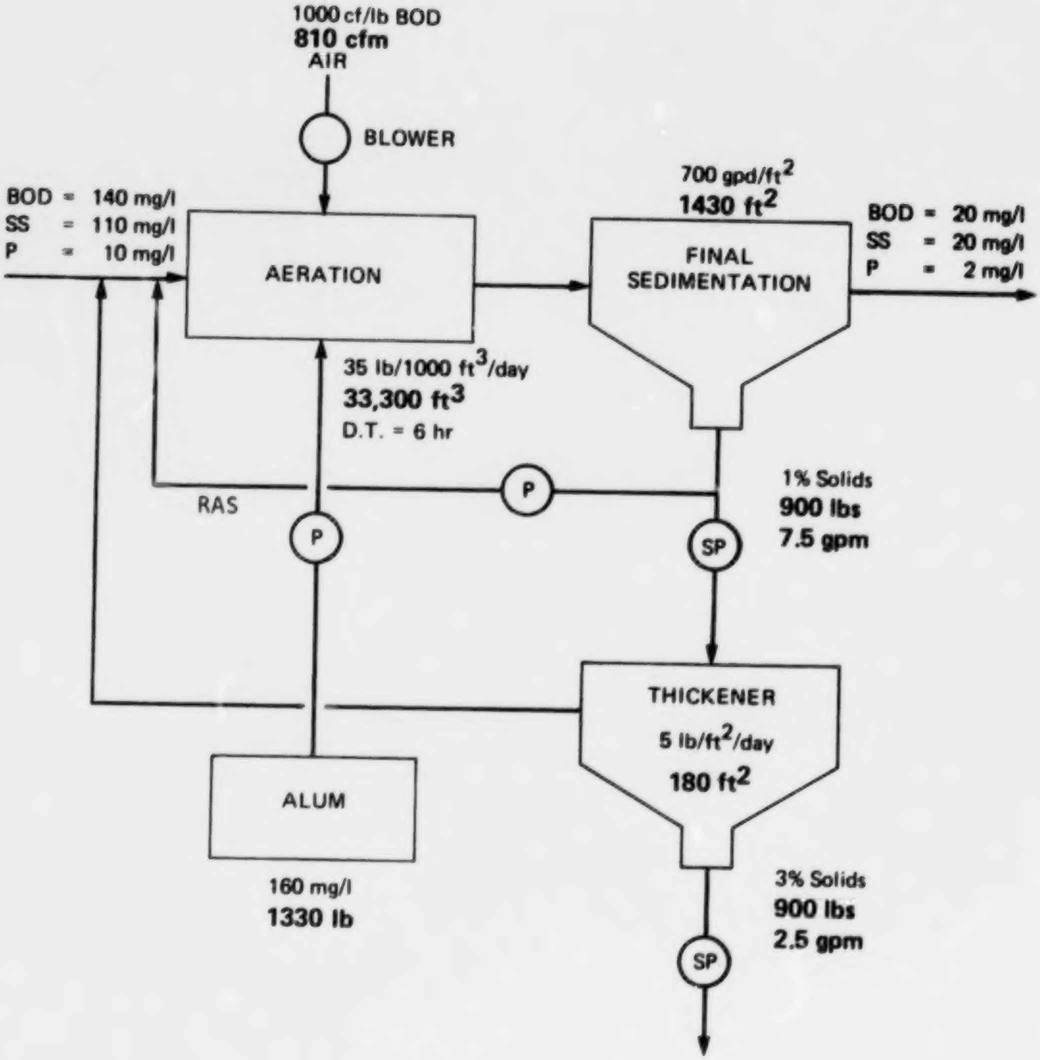
Influent: Effluent from Primary Sedimentation – Alum or $FeCl_3$ Addition A-4 or A-5


1000 cf/lb BOD
580 cfm
AIR
C
BOD = 100 mg/l
SS = 65 mg/l
P = 2.2 mg/l
AERATION
loading = 35 lb BOD/1000 ft3/day
22,300 ft3
DT = 4 hr
RAS
P
700 gpd/ft2
1430 ft2
FINAL SEDIMENTATION
BOD = 15 mg/l
SS = 15 mg/l
P = 1.8 mg/l
0.8% Solids
350 lbs
3.5 gpm
SP
THICKENER
5 lb/ft2/day
70 ft2
3% Solids
350 lbs
1.0 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

C-4. ACTIVATED SLUDGE + ALUM ADDITION

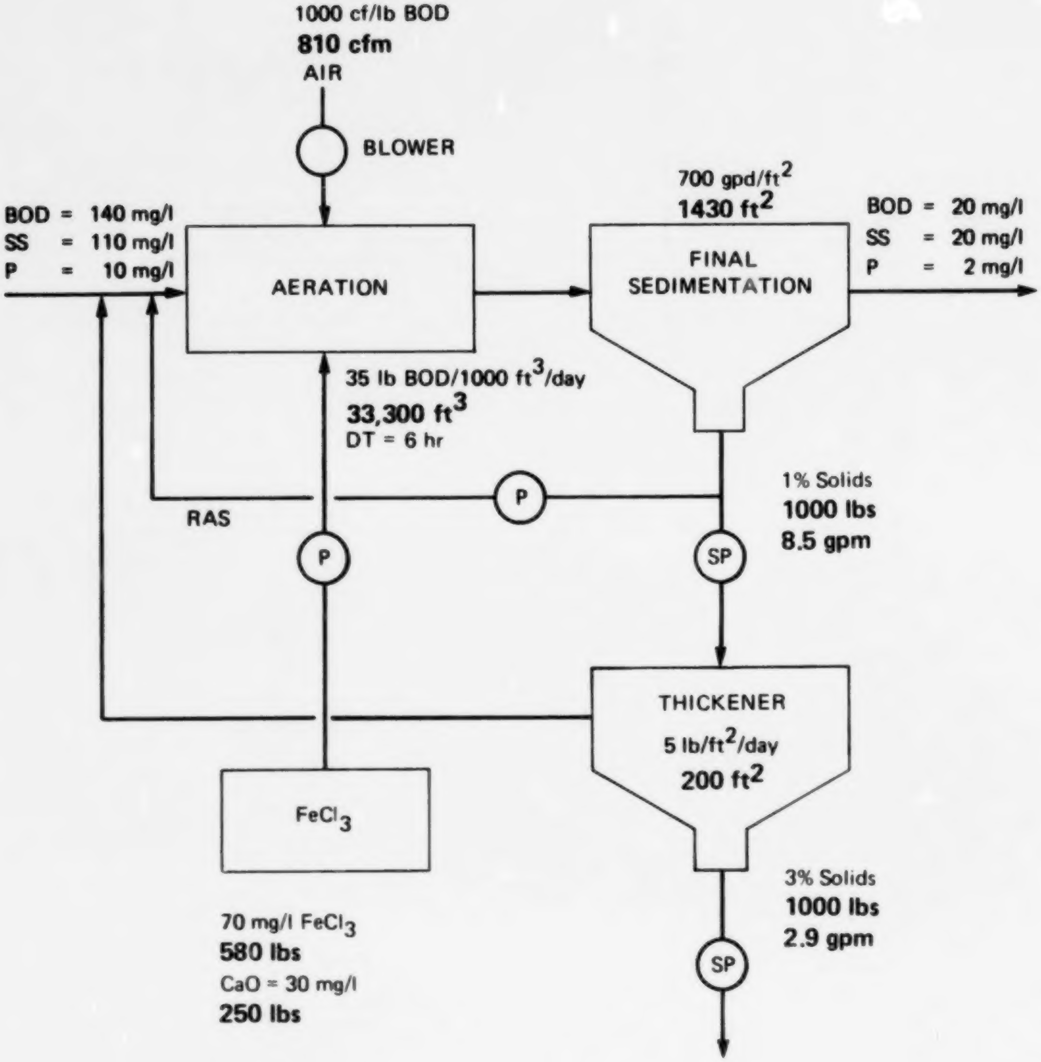
Influent: Effluent From Primary Sedimentation – Conventional A-1


1000 cf/lb BOD
810 cfm
AIR
BLOWER
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
AERATION
700 gpd/ft²
1430 ft²
FINAL SEDIMENTATION
BOD = 20 mg/l
SS = 20 mg/l
P = 2 mg/l
35 lb/1000 ft³/day
33,300 ft³
D.T. = 6 hr
RAS
P
P
1% Solids
900 lbs
7.5 gpm
SP
THICKENER
5 lb/ft²/day
180 ft²
ALUM
160 mg/l
1330 lb
3% Solids
900 lbs
2.5 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

C-5. ACTIVATED SLUDGE – $FeCl_3$ ADDITION

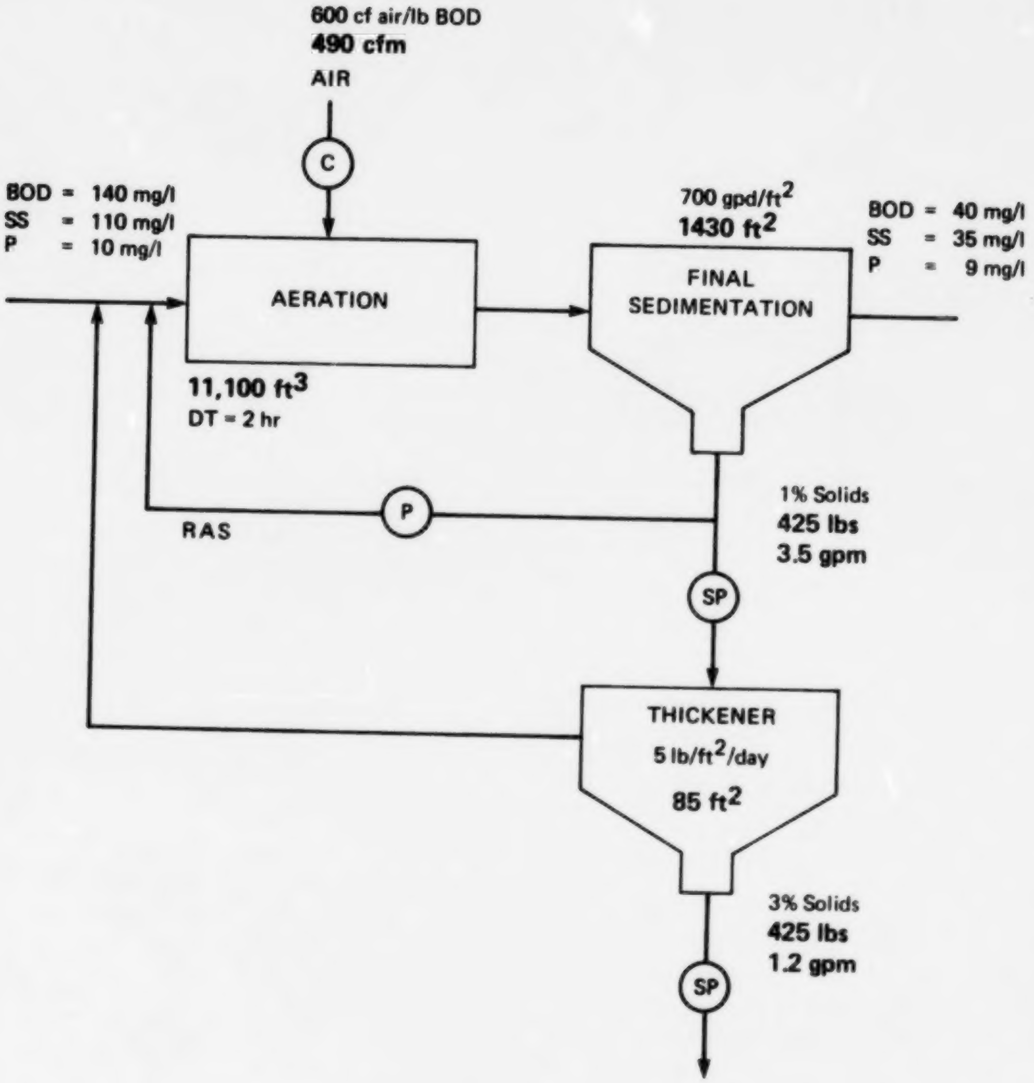
Influent: Effluent from Primary Sedimentation – Conventional A-1


1000 cf/lb BOD
810 cfm
AIR
BLOWER
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
AERATION
700 gpd/ft²
1430 ft²
FINAL SEDIMENTATION
BOD = 20 mg/l
SS = 20 mg/l
P = 2 mg/l
35 lb BOD/1000 ft³/day
33,300 ft³
DT = 6 hr
RAS
P
P
1% Solids
1000 lbs
8.5 gpm
SP
THICKENER
5 lb/ft²/day
200 ft²
FeCl3
3% Solids
1000 lbs
2.9 gpm
SP
70 mg/l FeCl3
580 lbs
CaO = 30 mg/l
250 lbs

Design criteria in bold type are per mgd influent wastewater flow.

C-6. ACTIVATED SLUDGE – HIGH RATE

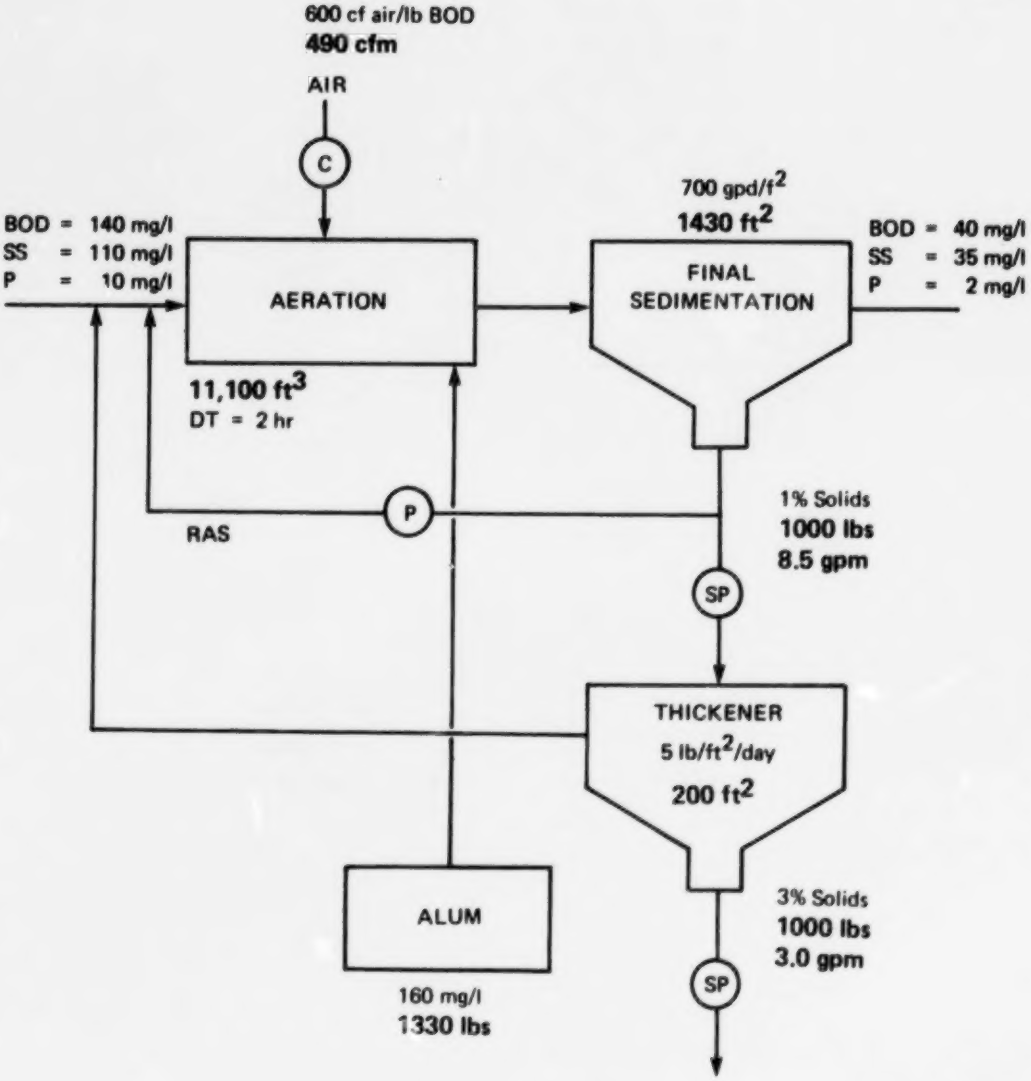
Influent: Effluent from Primary Sedimentation – Conventional A-1


600 cf air/lb BOD
490 cfm
AIR
C
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
AERATION
11,100 ft3
DT = 2 hr
700 gpd/ft2
1430 ft2
FINAL SEDIMENTATION
BOD = 40 mg/l
SS = 35 mg/l
P = 9 mg/l
P
RAS
1% Solids
425 lbs
3.5 gpm
SP
THICKENER
5 lb/ft2/day
85 ft2
3% Solids
425 lbs
1.2 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow

C-7. ACTIVATED SLUDGE – HIGH RATE + ALUM ADDITION

Influent: Effluent from Primary Sedimentation – Conventional A-1

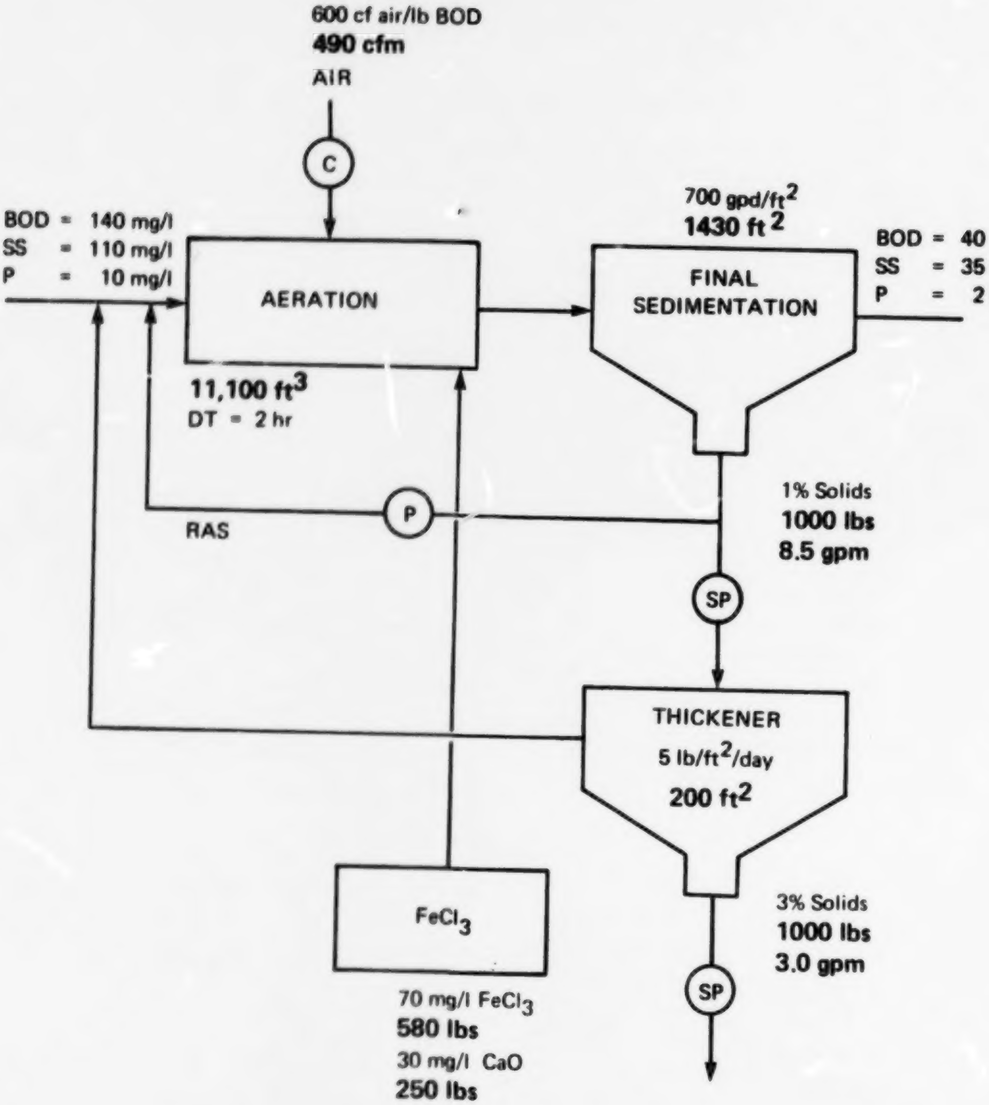


600 cf air/lb BOD
490 cfm
AIR
C
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
AERATION
11,100 ft3
DT = 2 hr
700 gpd/f2
1430 ft2
FINAL SEDIMENTATION
BOD = 40 mg/l
SS = 35 mg/l
P = 2 mg/l
P
RAS
1% Solids
1000 lbs
8.5 gpm
SP
THICKENER
5 lb/ft2/day
200 ft2
ALUM
160 mg/l
1330 lbs
3% Solids
1000 lbs
3.0 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow

C-8. ACTIVATED SLUDGE – HIGH RATE + $FeCl_3$ ADDITION

Influent: Effluent from Primary Sedimentation – Conventional A-1



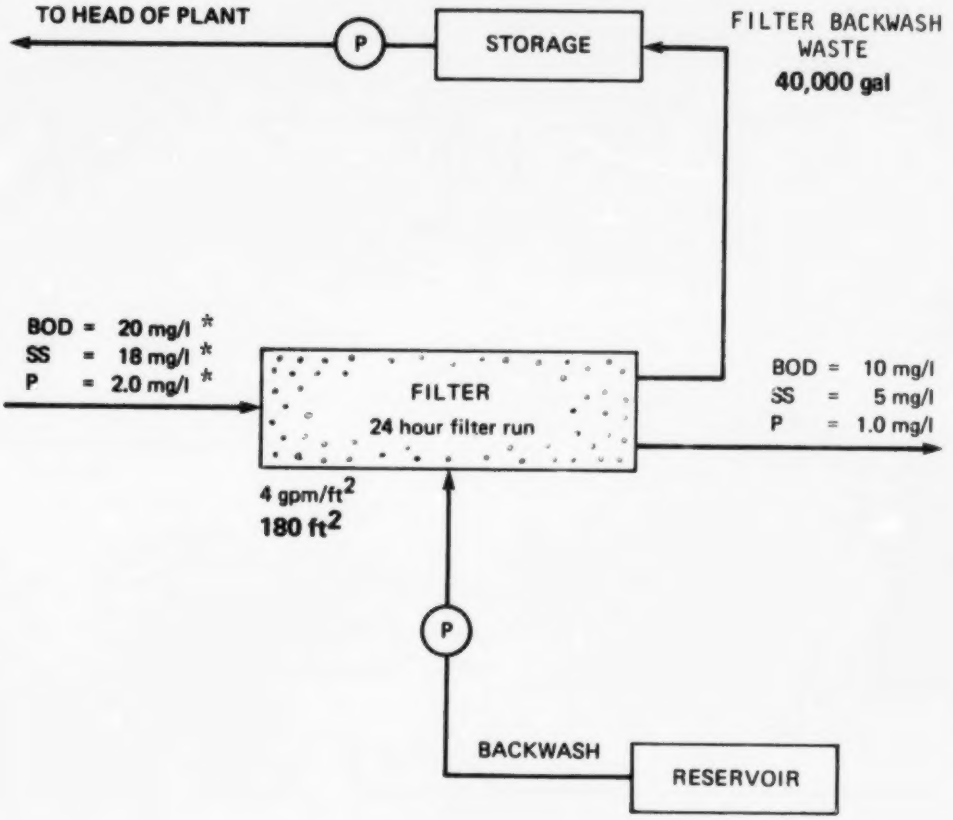
600 cf air/lb BOD
490 cfm
AIR
C
BOD = 140 mg/l
SS = 110 mg/l
P = 10 mg/l
AERATION
11,100 ft^3
DT = 2 hr
700 gpd/ft^2
1430 ft^2
FINAL SEDIMENTATION
BOD = 40 mg/l
SS = 35 mg/l
P = 2 mg/l
1% Solids
1000 lbs
8.5 gpm
P
RAS
SP
THICKENER
5 lb/ft^2/day
200 ft^2
3% Solids
1000 lbs
3.0 gpm
SP
$FeCl_3$
70 mg/l $FeCl_3$
580 lbs
30 mg/l CaO
250 lbs

Design criteria in bold type are per mgd influent wastewater flow

D. FILTRATION

Influent:

- Effluent from Primary Sedimentation – Two Stage Lime Addition A-2
- Activated Sludge – Alum or $FeCl_3$ Addition C-4 or C-5
- Two Stage Tertiary Lime Treatment F-1 or F-2
- Trickling Filter B-2, B-3
- Activated Sludge C-2, C-3
- Biological Nitrification G-1, G-2, G-3, G-4
- Biological Denitrification H
- Breakpoint Chlorination J
- Ammonia Stripping K

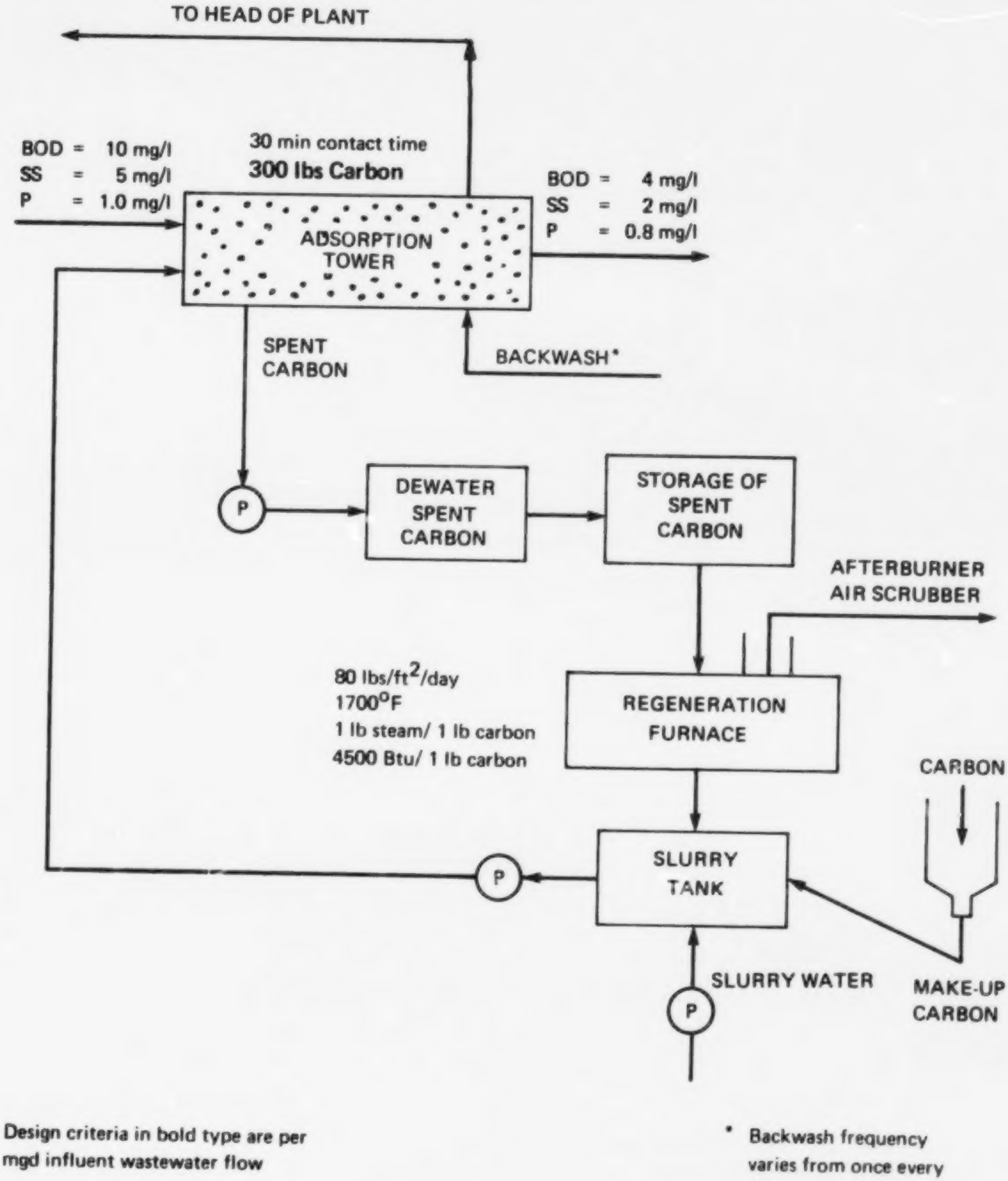

TO HEAD OF PLANT
P
STORAGE
FILTER BACKWASH WASTE
40,000 gal
BOD = 20 mg/l *
SS = 18 mg/l *
P = 2.0 mg/l *
FILTER
24 hour filter run
BOD = 10 mg/l
SS = 5 mg/l
P = 1.0 mg/l
4 gpm/ft²
180 ft²
P
BACKWASH
RESERVOIR

*Averaged values from above influent.

Design criteria in bold type are per
mgd influent wastewater flow

E. ACTIVATED CARBON

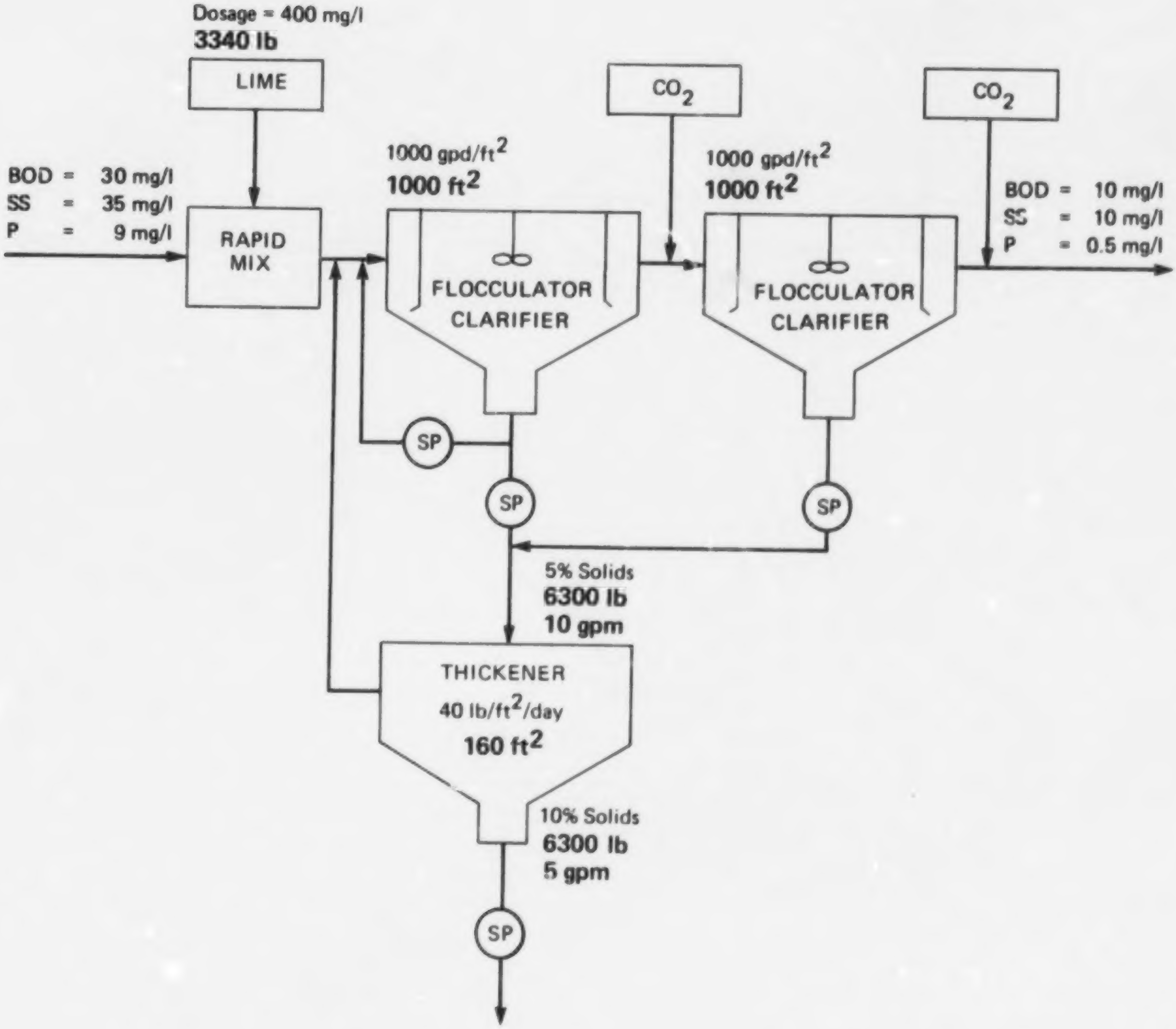
Influent: Effluent from Filtration D


TO HEAD OF PLANT
BOD = 10 mg/l
SS = 5 mg/l
P = 1.0 mg/l
30 min contact time
300 lbs Carbon
ADSORPTION TOWER
BOD = 4 mg/l
SS = 2 mg/l
P = 0.8 mg/l
SPENT CARBON
BACKWASH*
P
DEWATER SPENT CARBON
STORAGE OF SPENT CARBON
AFTERBURNER AIR SCRUBBER
80 lbs/ft2/day
1700°F
1 lb steam/ 1 lb carbon
4500 Btu/ 1 lb carbon
REGENERATION FURNACE
CARBON
SLURRY TANK
P
SLURRY WATER
P
MAKE-UP CARBON

Design criteria in bold type are per mgd influent wastewater flow

* Backwash frequency varies from once every 2 days to once every 2 weeks.

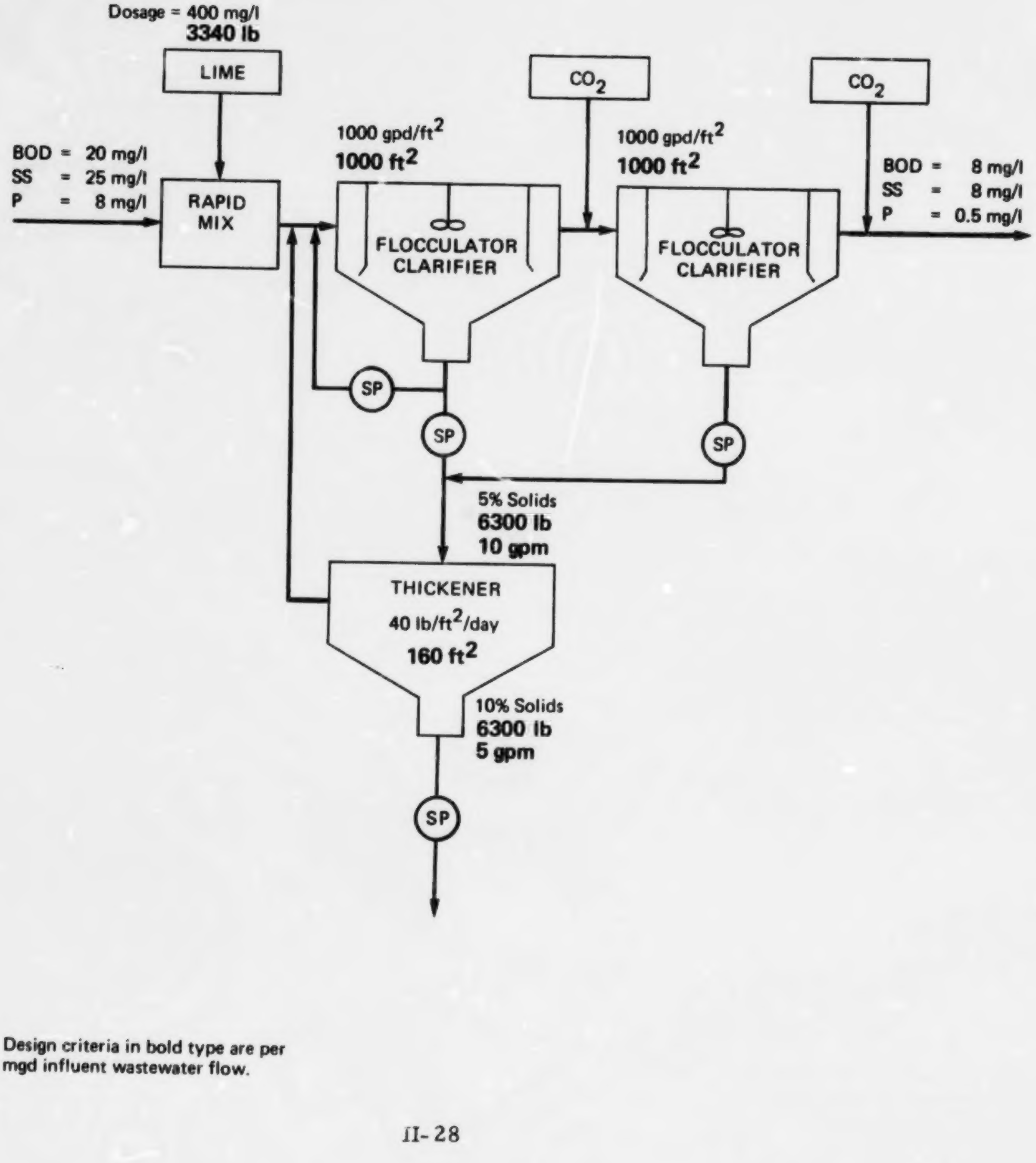
F-1. TWO-STAGE TERTIARY LIME TREATMENT
Influent: Effluent from Trickling Filter System B-1


Dosage = 400 mg/l
3340 lb
LIME
CO_2
CO_2
1000 gpd/ft^2
1000 ft^2
1000 gpd/ft^2
1000 ft^2
BOD = 30 mg/l
SS = 35 mg/l
P = 9 mg/l
RAPID MIX
FLOCCULATOR CLARIFIER
FLOCCULATOR CLARIFIER
BOD = 10 mg/l
SS = 10 mg/l
P = 0.5 mg/l
SP
SP
SP
5% Solids
6300 lb
10 gpm
THICKENER
40 lb/ft^2/day
160 ft^2
10% Solids
6300 lb
5 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

F-2. TWO-STAGE TERTIARY LIME TREATMENT

Influent: Effluent from Conventional Activated Sludge C-1

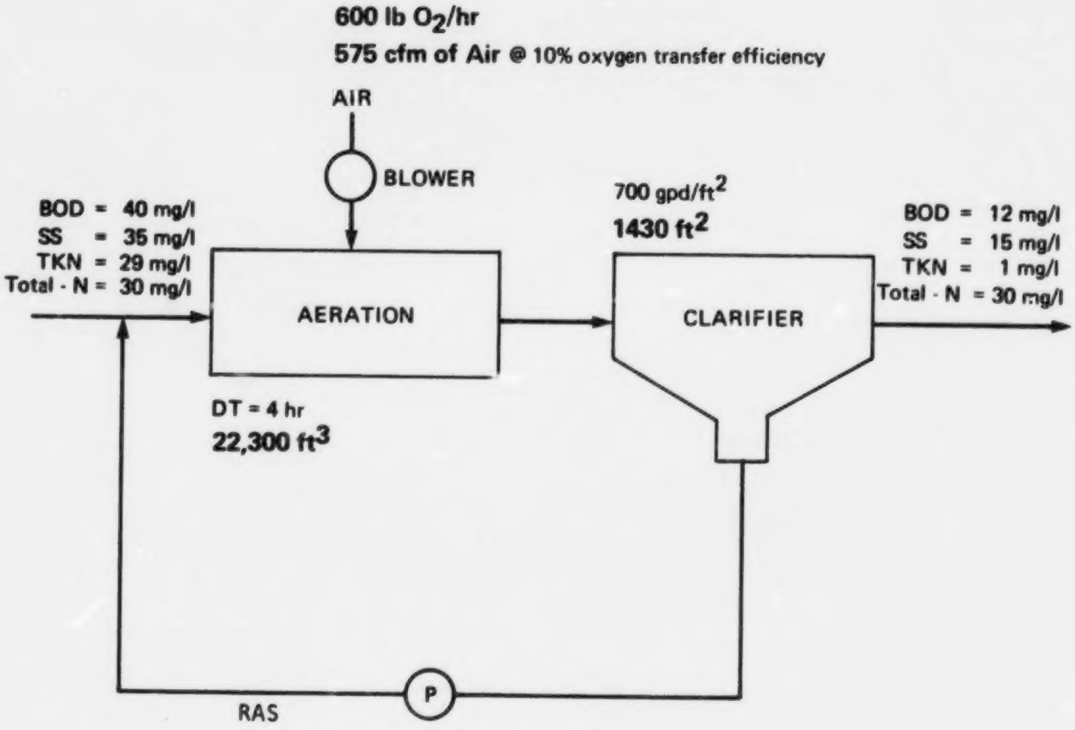


Dosage = 400 mg/l
3340 lb
LIME
BOD = 20 mg/l
SS = 25 mg/l
P = 8 mg/l
RAPID MIX
1000 gpd/ft2
1000 ft2
FLOCCULATOR CLARIFIER
CO2
1000 gpd/ft2
1000 ft2
FLOCCULATOR CLARIFIER
CO2
BOD = 8 mg/l
SS = 8 mg/l
P = 0.5 mg/l
SP
SP
SP
5% Solids
6300 lb
10 gpm
THICKENER
40 lb/ft2/day
160 ft2
10% Solids
6300 lb
5 gpm
SP

Design criteria in bold type are per mgd influent wastewater flow.

G-1. BIOLOGICAL NITRIFICATION

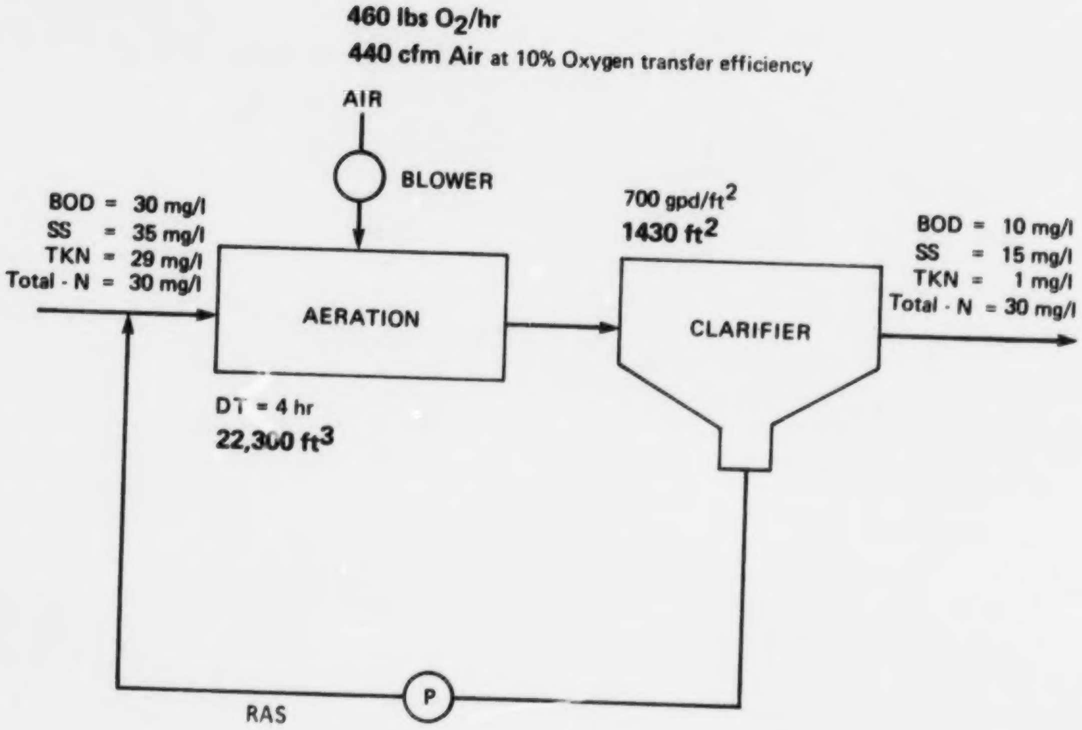
Influent: Effluent from High Rate Activated Sludge C-6


600 lb O_2/hr
575 cfm of Air @ 10% oxygen transfer efficiency
AIR
BLOWER
BOD = 40 mg/l
SS = 35 mg/l
TKN = 29 mg/l
Total - N = 30 mg/l
AERATION
DT = 4 hr
22,300 ft^3
700 gpd/ft^2
1430 ft^2
CLARIFIER
BOD = 12 mg/l
SS = 15 mg/l
TKN = 1 mg/l
Total - N = 30 mg/l
P
RAS

Design criteria in bold type are per mgd influent wastewater flow

G-2. BIOLOGICAL NITRIFICATION

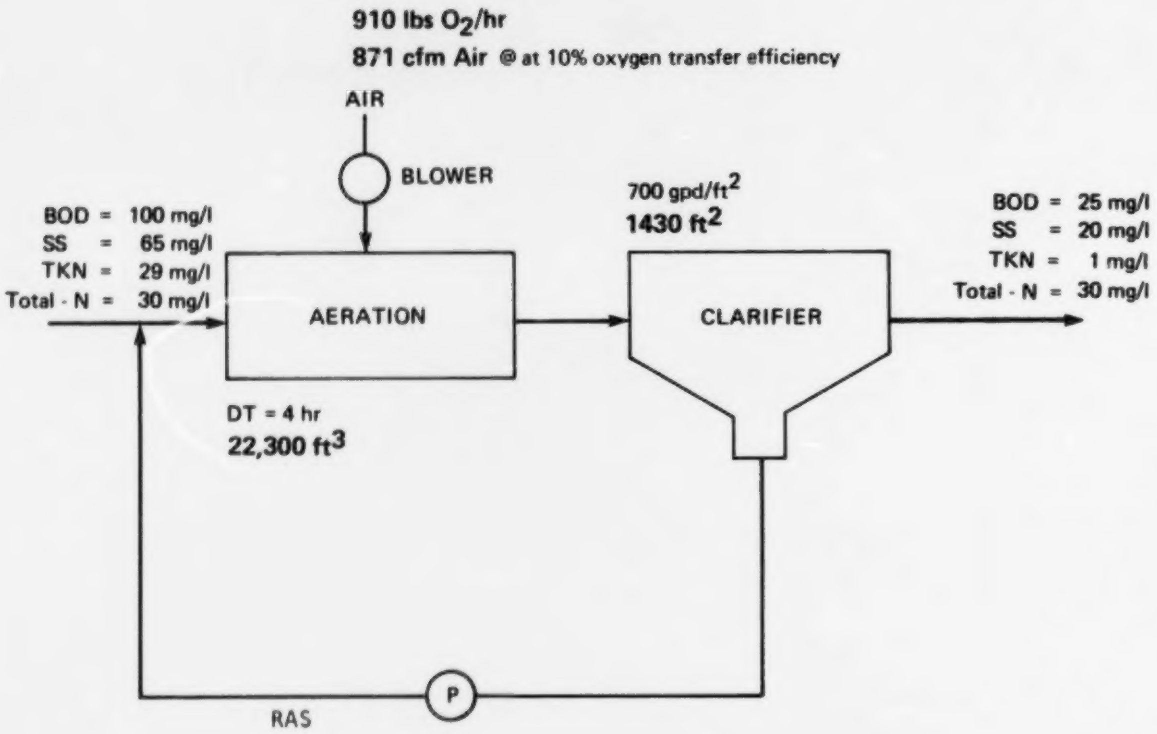
Influent: Effluent from Trickling Filter System B-1


460 lbs O2/hr
440 cfm Air at 10% Oxygen transfer efficiency
AIR
BLOWER
BOD = 30 mg/l
SS = 35 mg/l
TKN = 29 mg/l
Total - N = 30 mg/l
AERATION
DT = 4 hr
22,300 ft3
700 gpd/ft2
1430 ft2
CLARIFIER
BOD = 10 mg/l
SS = 15 mg/l
TKN = 1 mg/l
Total - N = 30 mg/l
P
RAS

Design criteria in bold type are per mgd influent wastewater flow

G-3. BIOLOGICAL NITRIFICATION

Influent: Effluent from Primary Sedimentation-Single Stage Lime Addition
A-3
Primary Sedimentation – Alum or $FeCl_3$ Addition
A-4 or A-5

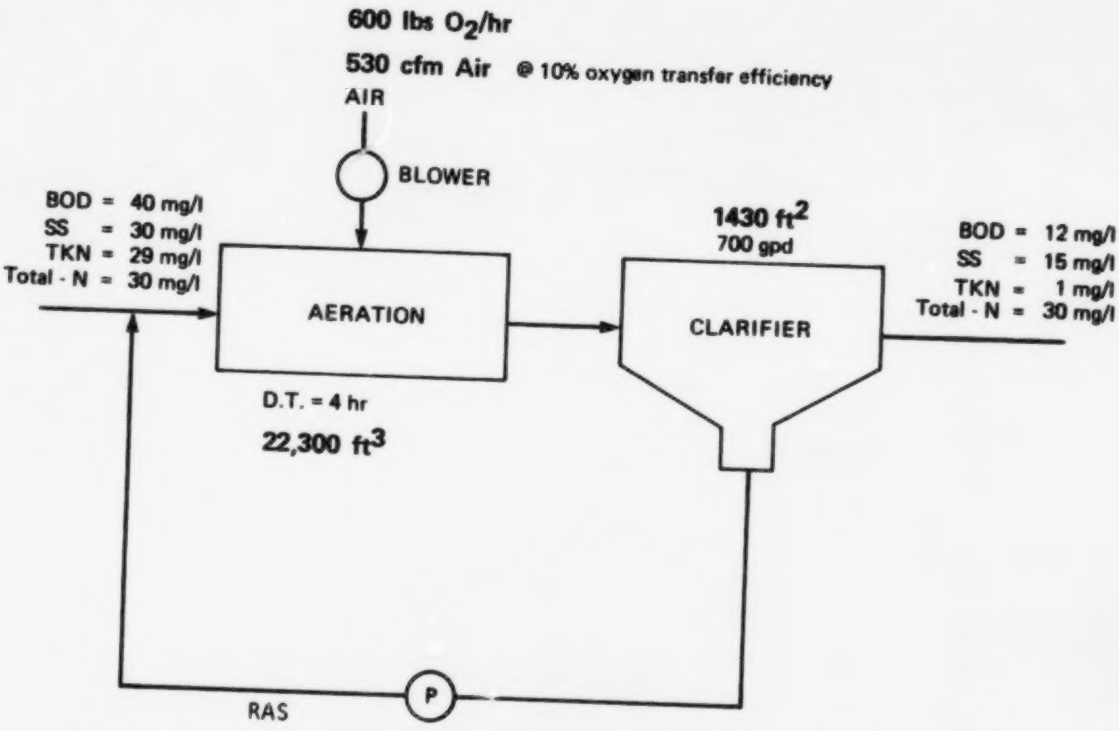


910 lbs O_2/hr
871 cfm Air @ at 10% oxygen transfer efficiency
AIR
BLOWER
BOD = 100 mg/l
SS = 65 mg/l
TKN = 29 mg/l
Total - N = 30 mg/l
AERATION
DT = 4 hr
22,300 ft^3
700 gpd/ft^2
1430 ft^2
CLARIFIER
BOD = 25 mg/l
SS = 20 mg/l
TKN = 1 mg/l
Total - N = 30 mg/l
P
RAS

Design criteria in bold type are per mgd influent wastewater flow

G-4. BIOLOGICAL NITRIFICATION

Influent: **Effluent from Primary Sedimentation – 2 Stage Lime Addition A-2. or High rate Activated Sludge + Alum or $FeCl_3$ Addition C-7 or C-8**



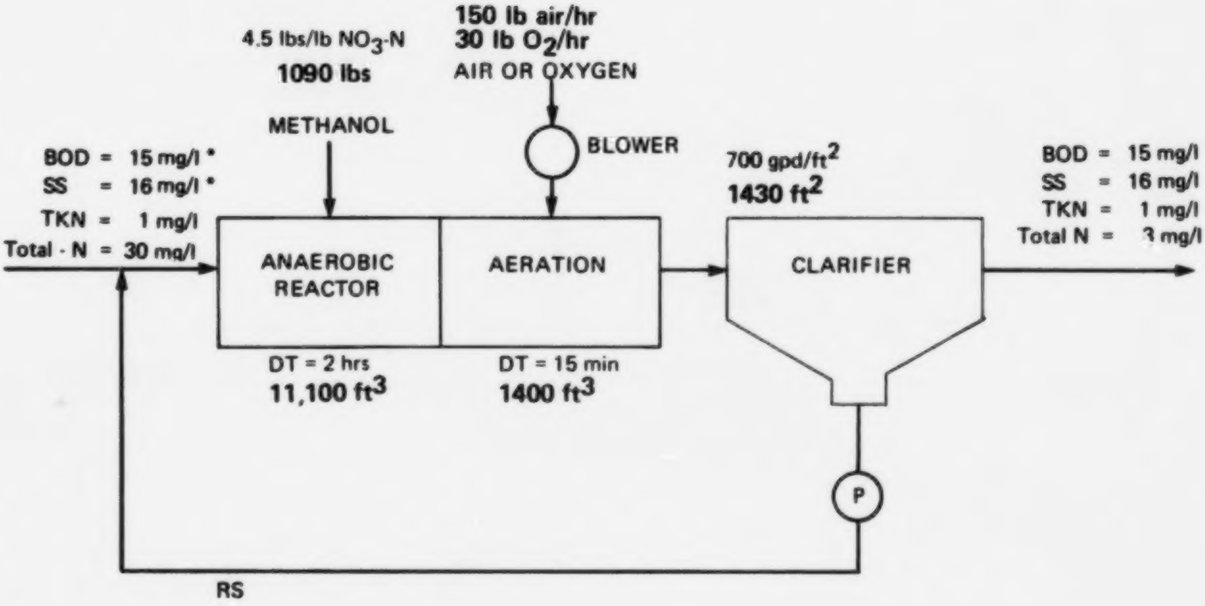
600 lbs O_2/hr
530 cfm Air @ 10% oxygen transfer efficiency
AIR
BLOWER
BOD = 40 mg/l
SS = 30 mg/l
TKN = 29 mg/l
Total - N = 30 mg/l
AERATION
D.T. = 4 hr
22,300 ft^3
1430 ft^2
700 gpd
CLARIFIER
BOD = 12 mg/l
SS = 15 mg/l
TKN = 1 mg/l
Total - N = 30 mg/l
P
RAS

Design criteria in bold type are per mgd influent wastewater flow

H. BIOLOGICAL DENITRIFICATION

Influent: Nitrification Process Effluents

G-1
G-2
G-3
G-4



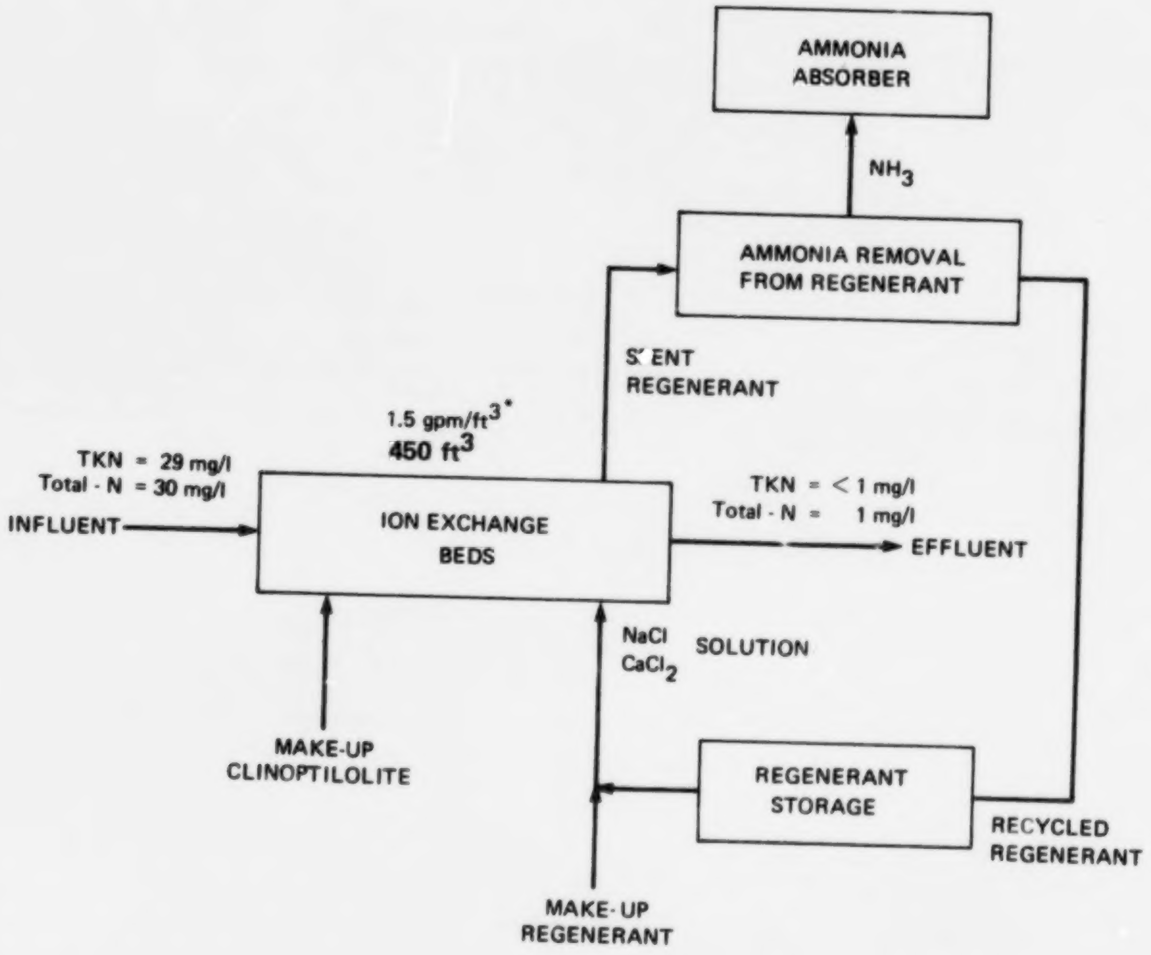
4.5 lbs/lb NO_3-N
1090 lbs
METHANOL
150 lb air/hr
30 lb O_2/hr
AIR OR OXYGEN
BLOWER
700 gpd/ft^2
1430 ft^2
BOD = 15 mg/l *
SS = 16 mg/l *
TKN = 1 mg/l
Total - N = 30 mg/l
ANAEROBIC REACTOR
AERATION
CLARIFIER
BOD = 15 mg/l
SS = 16 mg/l
TKN = 1 mg/l
Total N = 3 mg/l
DT = 2 hrs
11,100 ft^3
DT = 15 min
1400 ft^3
P
RS

*Averaged from G-1 through G-4; the design parameters for H are independent of these values.

Design criteria in bold type are per mgd influent wastewater flow.

I. ION-EXCHANGE

Influent: Filtration - Effluent
D
Activated Carbon Treatment Effluent
E

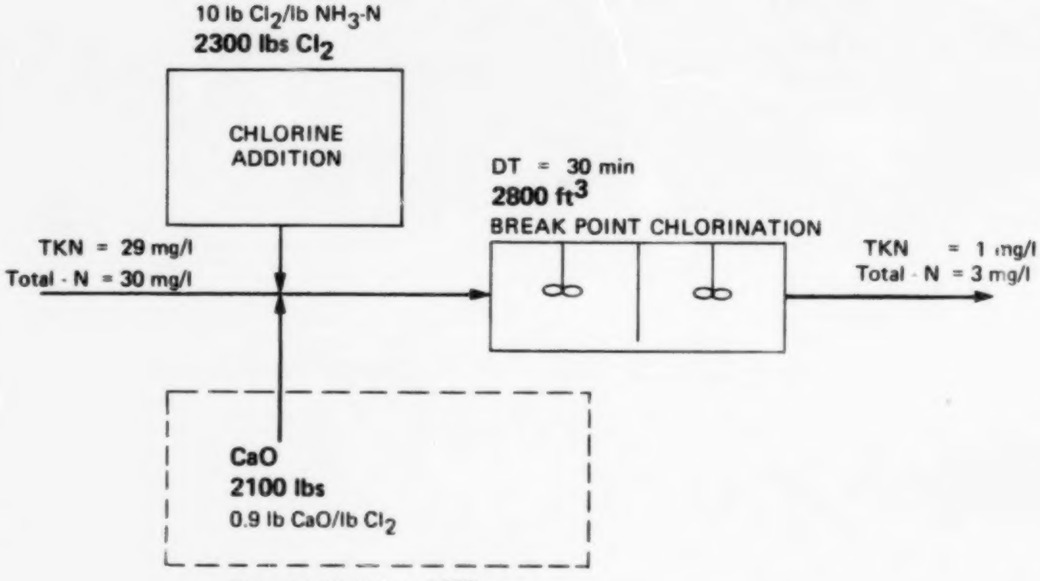

AMMONIA ABSORBER
NH_3
AMMONIA REMOVAL FROM REGENERANT
SPENT REGENERANT
1.5 gpm/ft^3*
450 ft^3
TKN = 29 mg/l
Total - N = 30 mg/l
INFLUENT
ION EXCHANGE BEDS
TKN = < 1 mg/l
Total - N = 1 mg/l
EFFLUENT
NaCl
$CaCl_2$
SOLUTION
MAKE-UP CLINOPTILOLITE
REGENERANT STORAGE
RECYCLED REGENERANT
MAKE-UP REGENERANT

* Length of service cycle approx. 175 bed volumes or every 15 hrs.
In service 95% of time, regenerating 5% of time.

Design criteria in bold type are per mgd influent wastewater flow

J. BREAK POINT CHLORINATION

Influent: Effluent from A-2, B-1, B-2, B-3, C-1, C-2, C-3, C-4, C-5, F-1, F-2

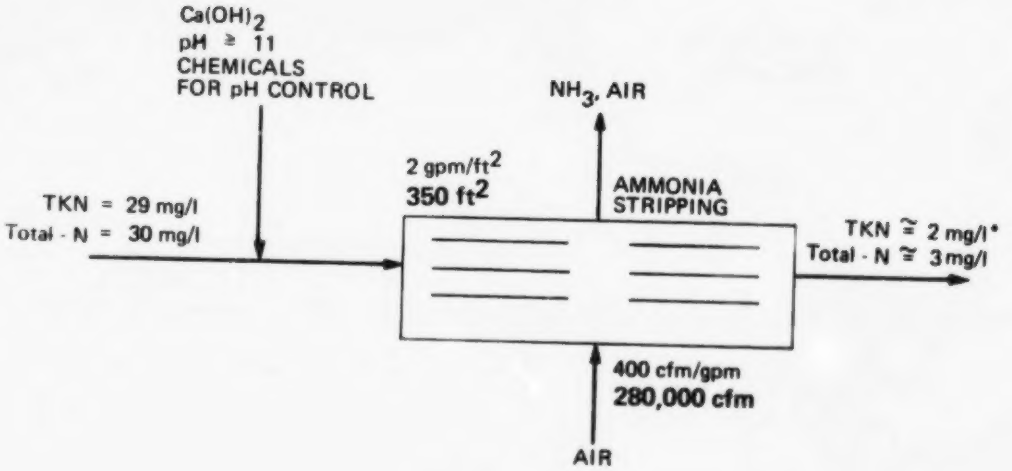

10 lb Cl_2/lb NH_3-N
2300 lbs Cl_2
CHLORINE ADDITION
DT = 30 min
2800 ft^3
BREAK POINT CHLORINATION
TKN = 29 mg/l
Total - N = 30 mg/l
TKN = 1 mg/l
Total - N = 3 mg/l
CaO
2100 lbs
0.9 lb CaO/lb Cl_2

Assumed alkalinity of 200 ppm

Design criteria in bold type are per mgd influent wastewater flow.

K. AMMONIA STRIPPING

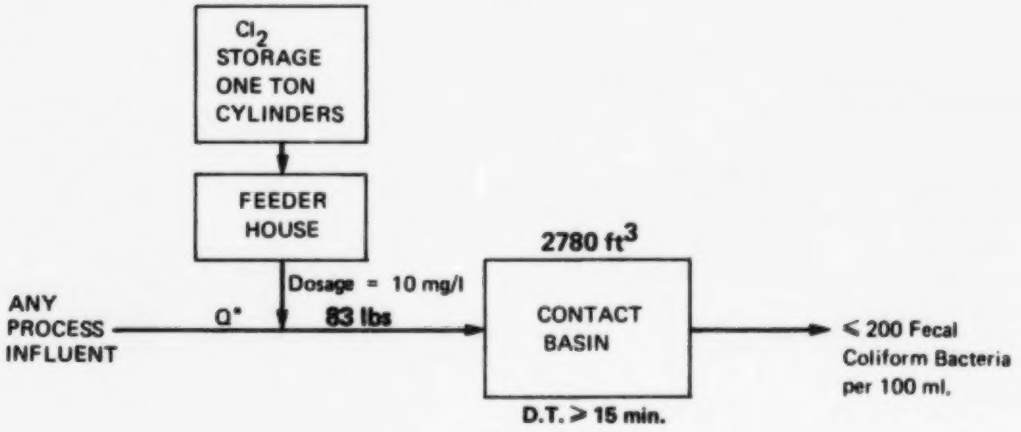
Influent: Effluent from First Stage of Two Stage Tertiary Lime Treatment F-1 or F-2


$Ca(OH)_2$
pH ≥ 11
CHEMICALS
FOR pH CONTROL
NH_3, AIR
2 gpm/ft^2
350 ft^2
AMMONIA
STRIPPING
TKN = 29 mg/l
Total - N = 30 mg/l
TKN ≅ 2 mg/l*
Total - N ≅ 3 mg/l
400 cfm/gpm
280,000 cfm
AIR

*90% removal efficiency at 80°F ambient air temperature

Design criteria in bold type are per mgd influent wastewater flow.

R. DISINFECTION
Influent: Any Process Effluent



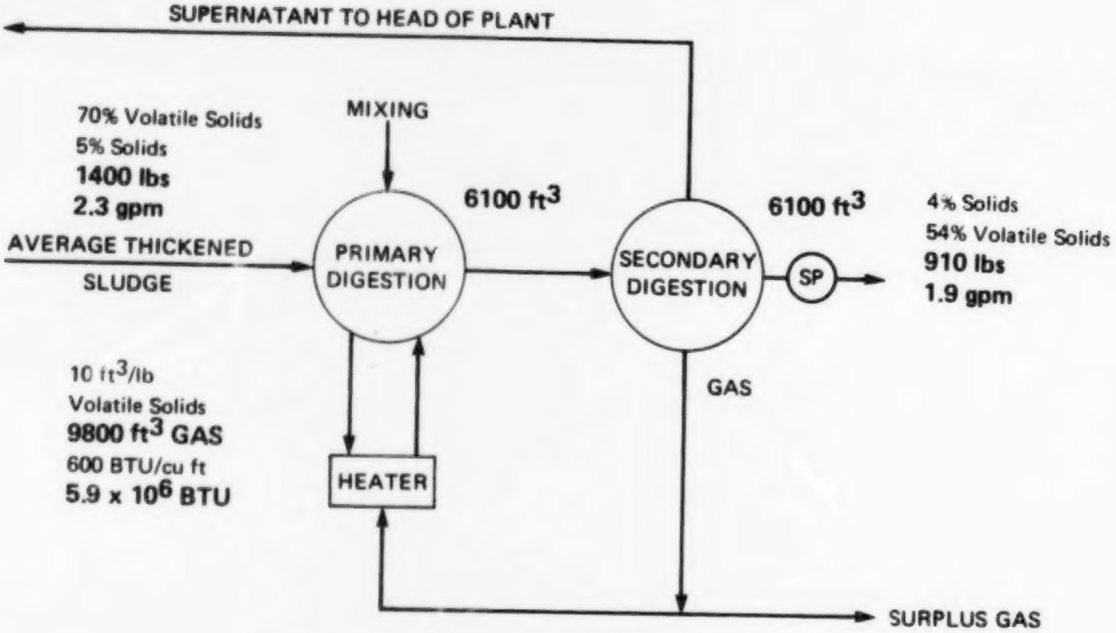
Cl_2 STORAGE ONE TON CYLINDERS
FEEDER HOUSE
Dosage = 10 mg/l
83 lbs
2780 ft^3
ANY PROCESS INFLUENT
Q*
CONTACT BASIN
D.T. ≥ 15 min.
≤ 200 Fecal Coliform Bacteria per 100 ml.

*Peak Flow = 2Q

Design criteria in bold type are per mgd influent wastewater flow.

L-1. ANAEROBIC DIGESTION

Sludge Influent: Primary Sedimentation – Conventional plus Trickling Filter
A-1 + B-1
Primary Sedimentation – Conventional plus Activated Sludge – Conventional
A-1 + C-1
Primary Sedimentation – Conventional plus Activated Sludge – High rate
A-1 + C-6

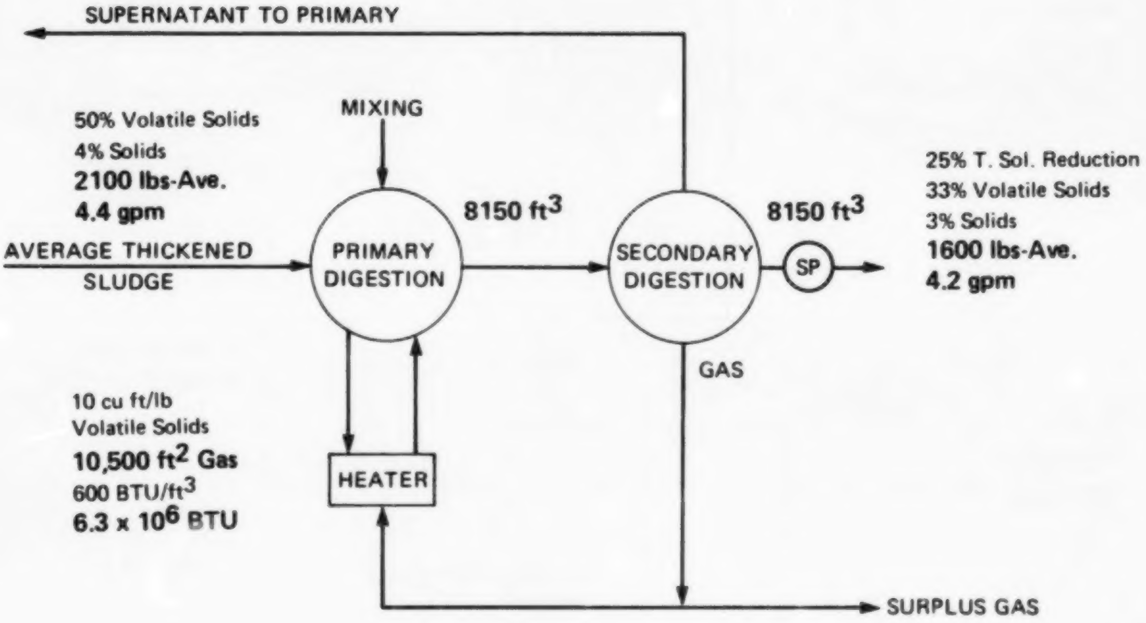

SUPERNATANT TO HEAD OF PLANT
70% Volatile Solids
5% Solids
1400 lbs
2.3 gpm
AVERAGE THICKENED SLUDGE
MIXING
PRIMARY DIGESTION
6100 ft3
SECONDARY DIGESTION
6100 ft3
SP
4% Solids
54% Volatile Solids
910 lbs
1.9 gpm
10 ft3/lb
Volatile Solids
9800 ft3 GAS
600 BTU/cu ft
5.9 x 106 BTU
HEATER
GAS
SURPLUS GAS

Digestor capacity calculation based on Volatile Solids loading factor of 0.16 lb/day/cuft

Design criteria in bold type are per mgd influent wastewater flow.

L-2. ANAEROBIC DIGESTION

Sludge Influent: Primary Sedimentation – Conventional and Activated Sludge
or High Rate Activated Sludge – Alum or $FeCl_3$ Addition
A-1 + C-4 or C-5
A-1 + C-7 or C-8
Primary Sedimentation – Alum or $FeCl_3$ Addition + Activated
Sludge or Trickling Filter
A-4 + B-3 or C-3
A-5 + B-3 or C-3


SUPERNATANT TO PRIMARY
50% Volatile Solids
4% Solids
2100 lbs-Ave.
4.4 gpm
MIXING
AVERAGE THICKENED SLUDGE
PRIMARY DIGESTION
8150 ft^3
SECONDARY DIGESTION
8150 ft^3
SP
25% T. Sol. Reduction
33% Volatile Solids
3% Solids
1600 lbs-Ave.
4.2 gpm
GAS
10 cu ft/lb
Volatile Solids
10,500 ft^2 Gas
600 BTU/ft^3
6.3 x 10^6 BTU
HEATER
SURPLUS GAS

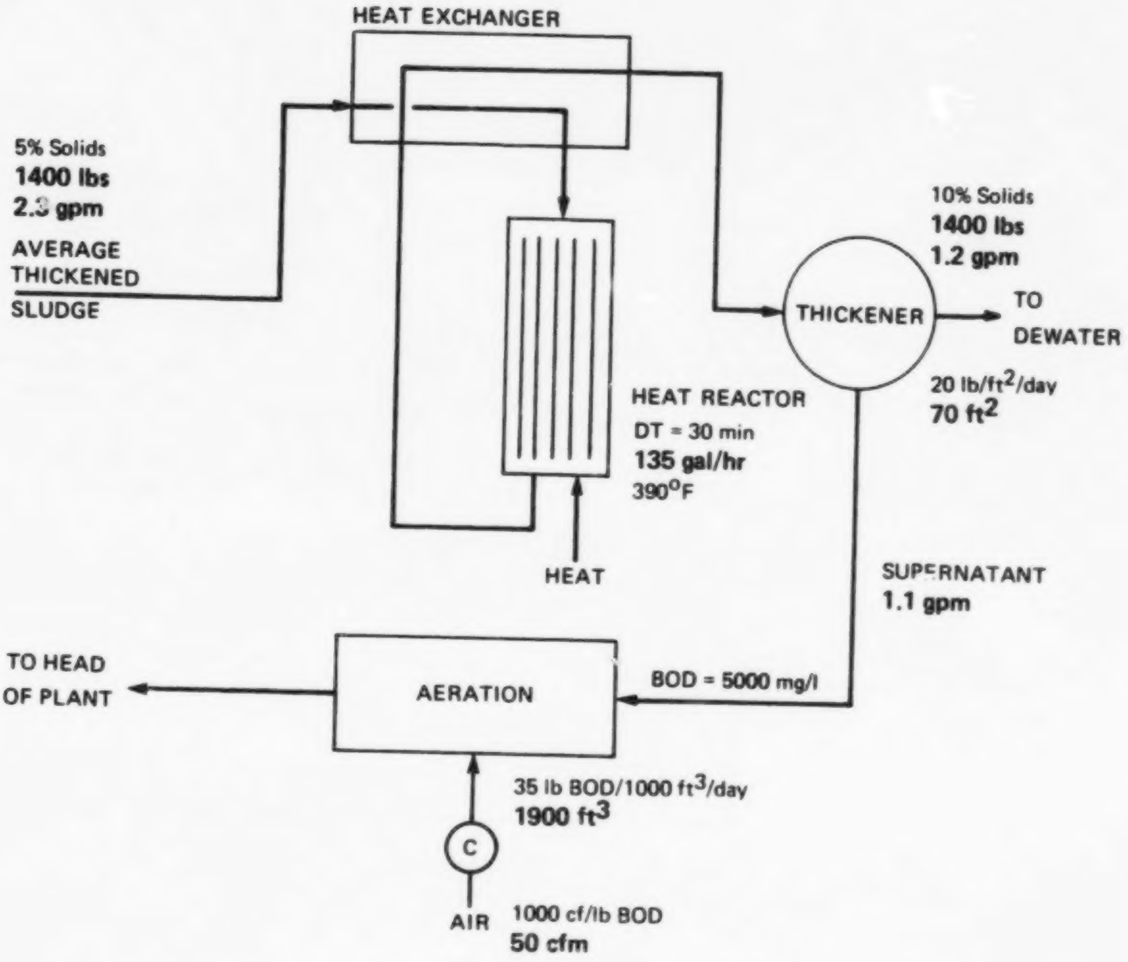
Digestor capacity based on Volatile Solids
loading factor of 0.129 lb/day/cu ft

Design criteria in bold type are per
mgd influent wastewater flow.

M-1. HEAT TREATMENT

Sludge Influent: Biological Primary + Secondary – Conventional or High rate
A-1 + B-1
A-1 + C-1
A-1 + C-6

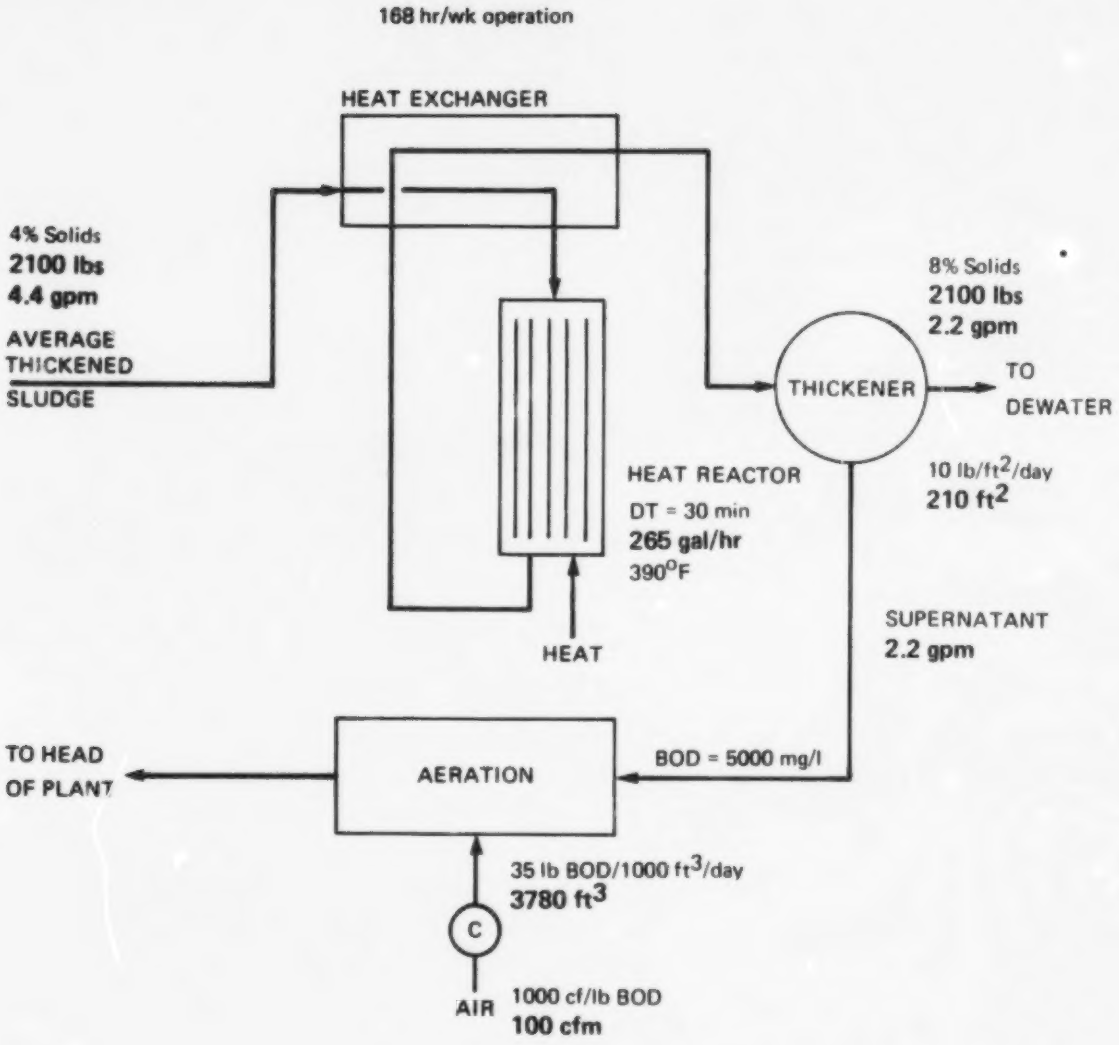
168 hr/wk Operation


HEAT EXCHANGER
5% Solids
1400 lbs
2.3 gpm
AVERAGE
THICKENED
SLUDGE
10% Solids
1400 lbs
1.2 gpm
THICKENER
TO
DEWATER
20 lb/ft2/day
70 ft2
HEAT REACTOR
DT = 30 min
135 gal/hr
390°F
HEAT
SUPERNATANT
1.1 gpm
TO HEAD
OF PLANT
AERATION
BOD = 5000 mg/l
35 lb BOD/1000 ft3/day
1900 ft3
C
AIR
1000 cf/lb BOD
50 cfm

Design criteria in bold type are per
mgd influent wastewater flow

M-2. HEAT TREATMENT

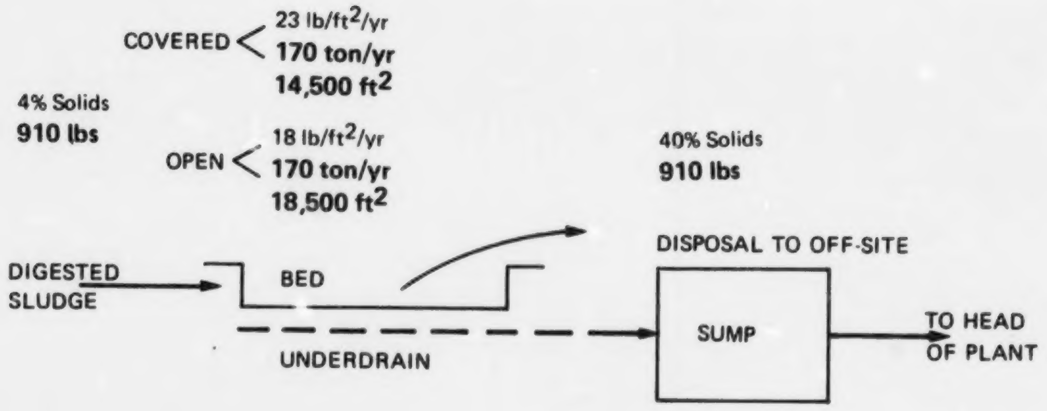
Sludge Influent: Primary Sedimentation + Activated Sludge or high rate activated sludge
A-1 + C-4 or C-5 – Alum or $FeCl_3$ Addition
A-1 + C-7 or C-8
Primary Sedimentation – Alum or $FeCl_3$ Addition + Activated Sludge or Trickling Filter
A-4 + B-3 or C-3
A-5 + B-3 or C-3


168 hr/wk operation
HEAT EXCHANGER
4% Solids
2100 lbs
4.4 gpm
AVERAGE THICKENED SLUDGE
8% Solids
2100 lbs
2.2 gpm
THICKENER
TO DEWATER
10 lb/ft²/day
210 ft²
HEAT REACTOR
DT = 30 min
265 gal/hr
390°F
HEAT
SUPERNATANT
2.2 gpm
TO HEAD OF PLANT
AERATION
BOD = 5000 mg/l
35 lb BOD/1000 ft³/day
3780 ft³
C
AIR
1000 cf/lb BOD
100 cfm

Design criteria in bold type are per mgd influent wastewater flow.

N-1. AIR DRYING

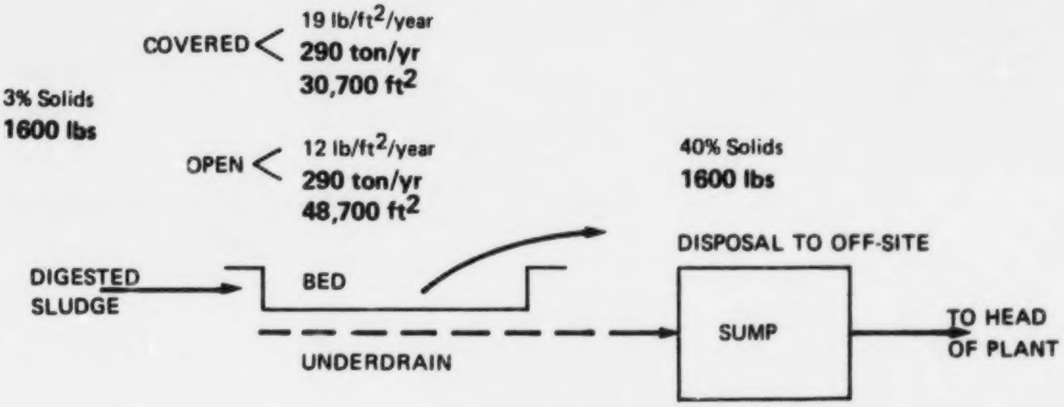
Sludge Influent: Digested Primary + Secondary — Conventional L-1


COVERED
23 lb/ft2/yr
170 ton/yr
14,500 ft2
4% Solids
910 lbs
OPEN
18 lb/ft2/yr
170 ton/yr
18,500 ft2
40% Solids
910 lbs
DISPOSAL TO OFF-SITE
DIGESTED SLUDGE
BED
SUMP
TO HEAD OF PLANT
UNDERDRAIN

Design criteria in bold type are per mgd influent wastewater flow.

N-2. AIR DRYING

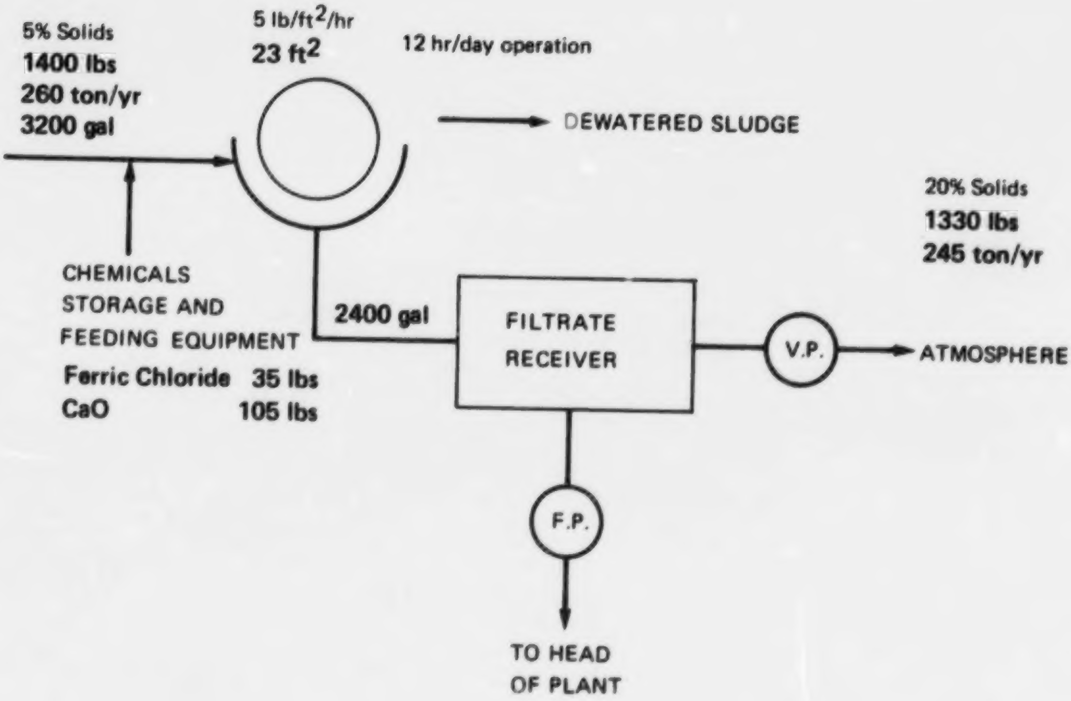
Sludge Influent: Digested Primary + Secondary (Alum or $FeCl_3$ Addition) L-2


COVERED
19 lb/ft²/year
290 ton/yr
30,700 ft²
3% Solids
1600 lbs
OPEN
12 lb/ft²/year
290 ton/yr
48,700 ft²
40% Solids
1600 lbs
DISPOSAL TO OFF-SITE
DIGESTED SLUDGE
BED
UNDERDRAIN
SUMP
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

O-1. DEWATERING

Sludge Influent: Primary + Secondary – Conventional or High rate
A-1 + B-1
A-1 + C-1
A-1 + C-6


5% Solids
1400 lbs
260 ton/yr
3200 gal
5 lb/ft2/hr
23 ft2
12 hr/day operation
DEWATERED SLUDGE
20% Solids
1330 lbs
245 ton/yr
CHEMICALS STORAGE AND FEEDING EQUIPMENT
Ferric Chloride 35 lbs
CaO 105 lbs
2400 gal
FILTRATE RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

O-2. DEWATERING

Sludge Influent: **Primary-Conventional + Secondary-Alum or $FeCl_3$ Addition**

A-1 + C-4 or C-5

A-1 + C-7 or C-8

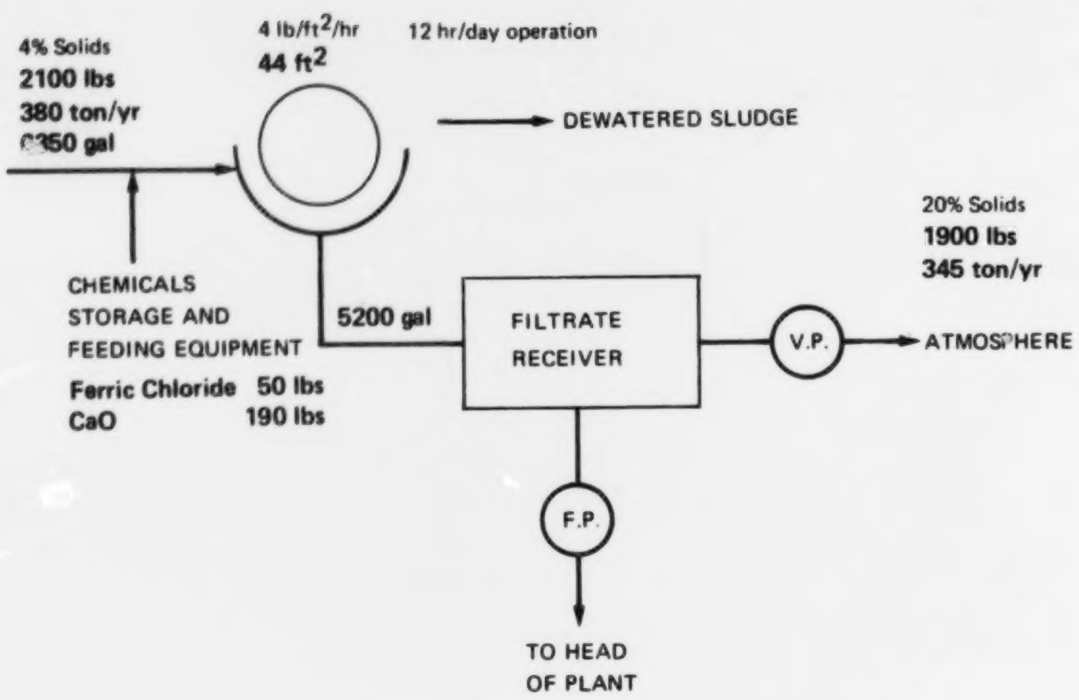
Primary-Alum or $FeCl_3$ Addition + Secondary

A-4 + B-3

A-4 + C-3

A-5 + B-3

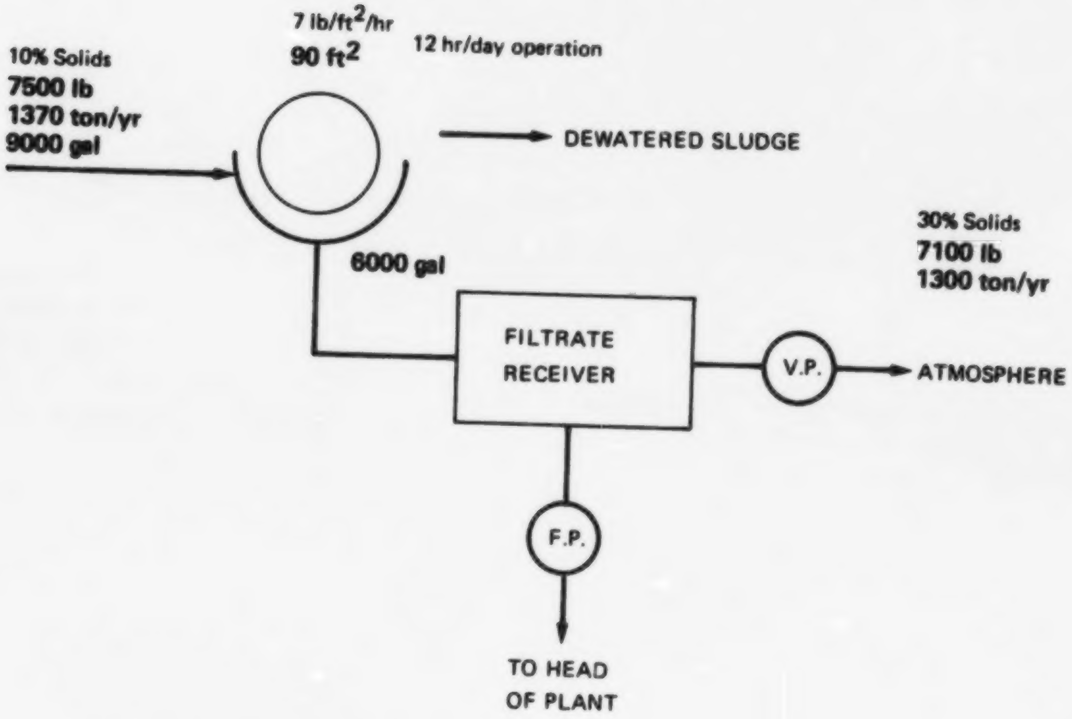
A-5 + C-3


4% Solids
2100 lbs
380 ton/yr
6350 gal
4 lb/ft²/hr
44 ft²
12 hr/day operation
DEWATERED SLUDGE
20% Solids
1900 lbs
345 ton/yr
CHEMICALS
STORAGE AND
FEEDING EQUIPMENT
Ferric Chloride 50 lbs
CaO 190 lbs
5200 gal
FILTRATE
RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD
OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

O-3. DEWATERING

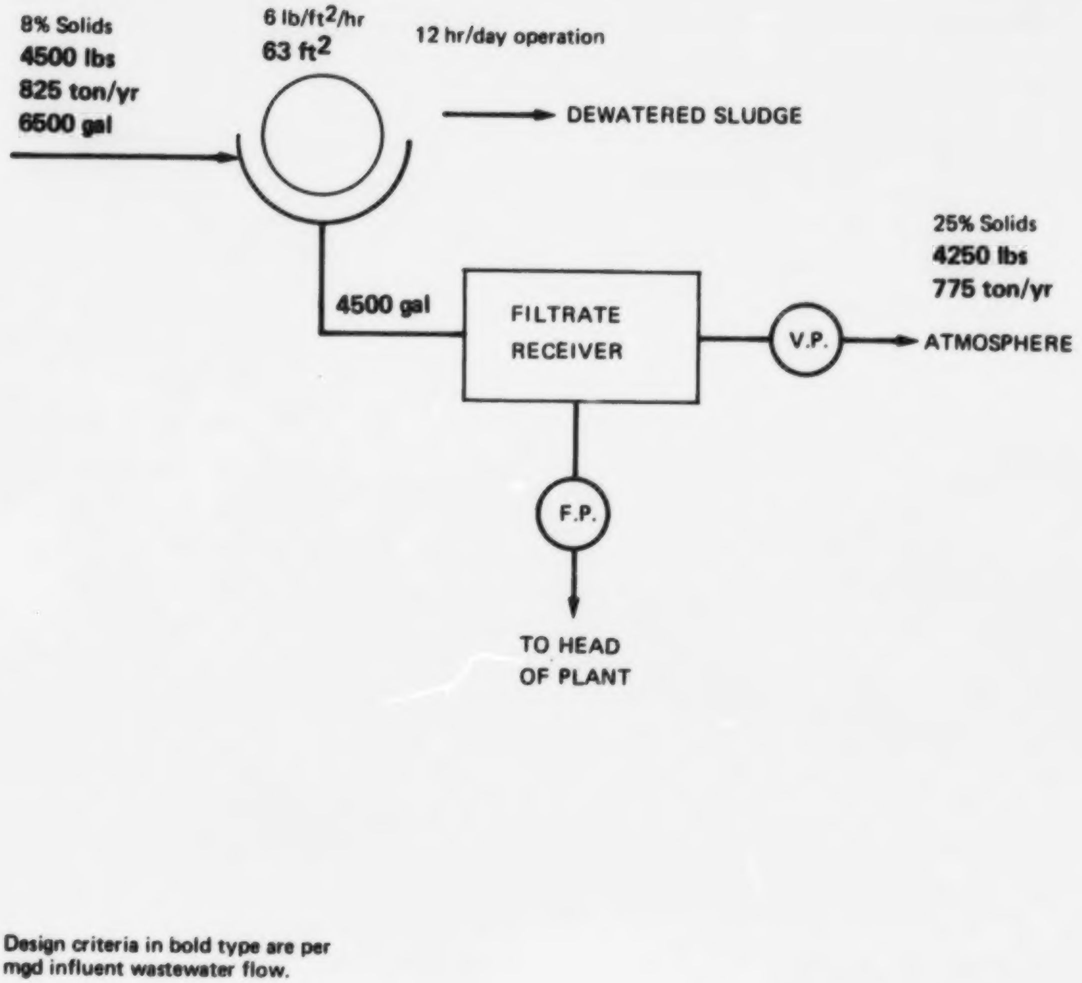
Sludge Influent: Primary Sedimentation – Two Stage Lime Addition A-2


10% Solids
7500 lb
1370 ton/yr
9000 gal
7 lb/ft²/hr
90 ft²
12 hr/day operation
DEWATERED SLUDGE
30% Solids
7100 lb
1300 ton/yr
6000 gal
FILTRATE RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

D-4. DEWATERING

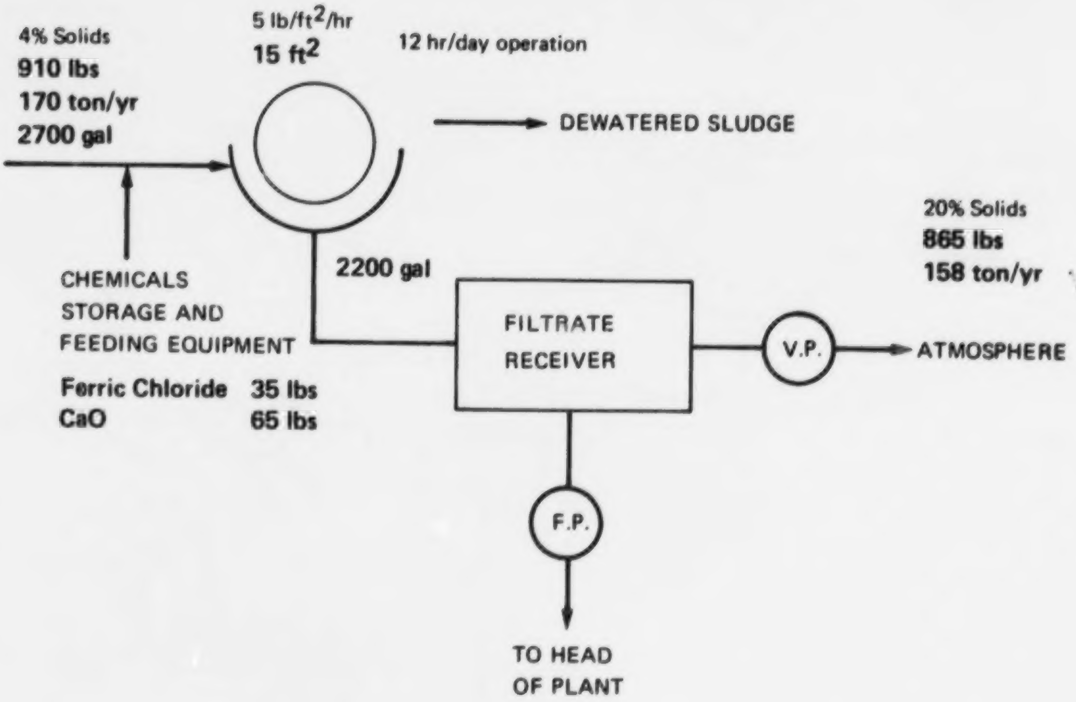
Sludge Influent: Primary Sedimentation – Single Stage Lime Addition
+ Trickling Filter or Activated Sludge
A-3 + B-2
A-3 + C-2


8% Solids
4500 lbs
825 ton/yr
6500 gal
6 lb/ft2/hr
63 ft2
12 hr/day operation
DEWATERED SLUDGE
25% Solids
4250 lbs
775 ton/yr
4500 gal
FILTRATE RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

O-5. DEWATERING

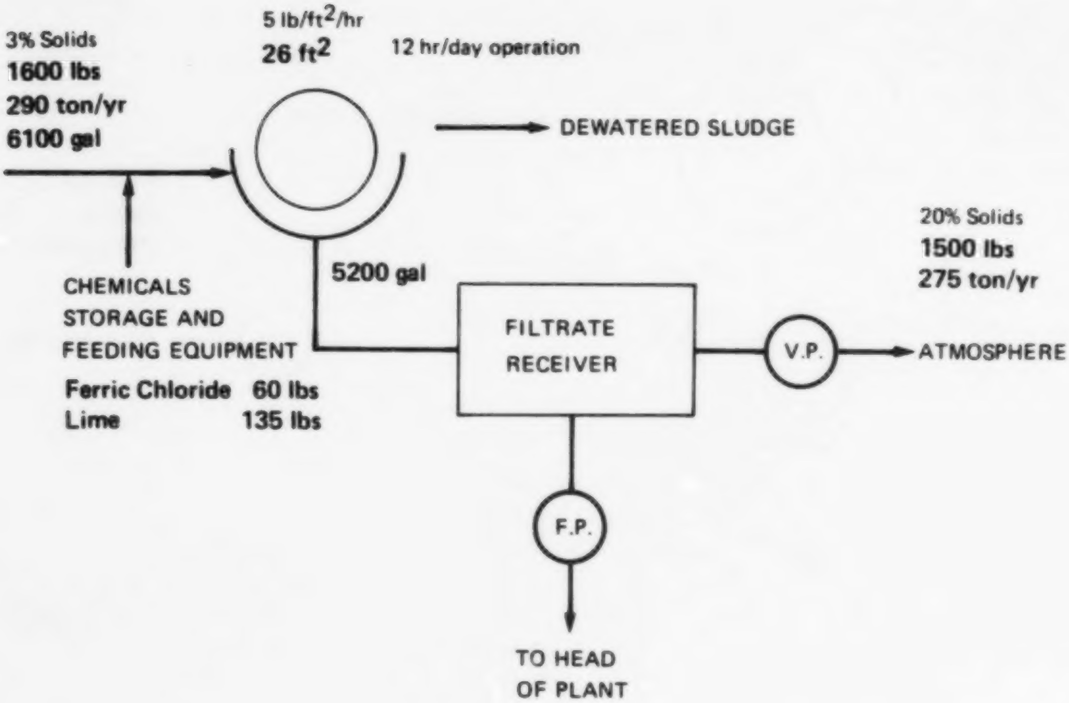
Sludge Influent: Digested Primary + Secondary – Conventional (L-1)


4% Solids
910 lbs
170 ton/yr
2700 gal
5 lb/ft²/hr
15 ft²
12 hr/day operation
DEWATERED SLUDGE
20% Solids
865 lbs
158 ton/yr
2200 gal
CHEMICALS
STORAGE AND
FEEDING EQUIPMENT
Ferric Chloride 35 lbs
CaO 65 lbs
FILTRATE
RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD
OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

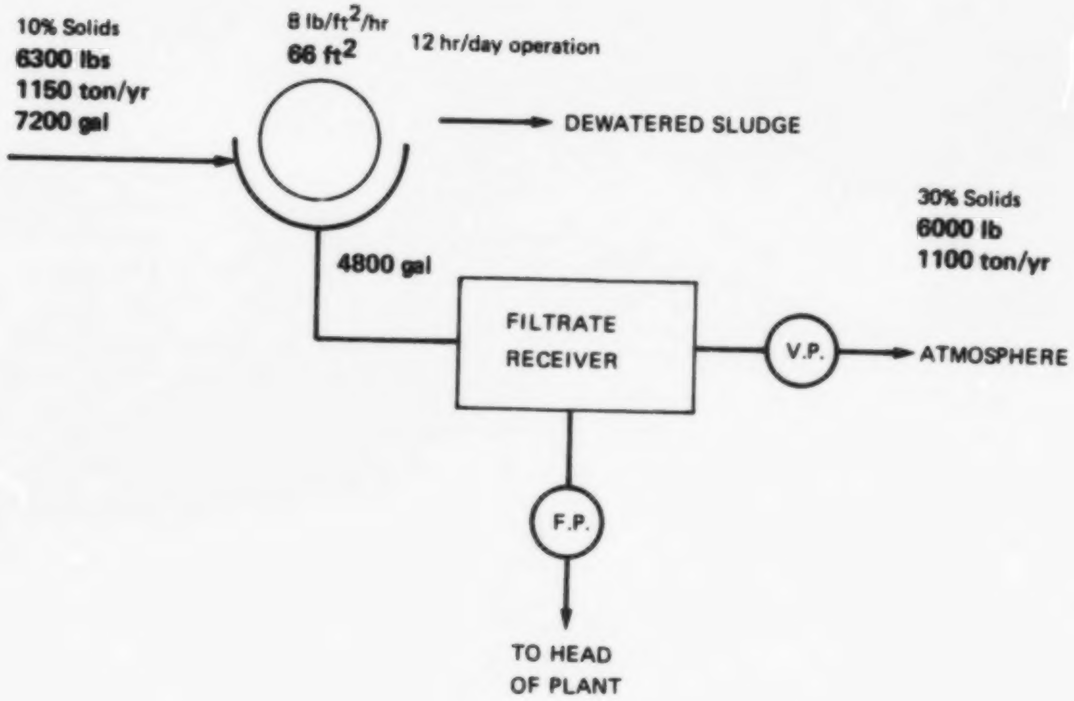
O-6. DEWATERING

Sludge Influent: Digested Primary + Secondary (Alum or $FeCl_3$ Addition) (L-2)


3% Solids
1600 lbs
290 ton/yr
6100 gal
5 lb/ft2/hr
26 ft2
12 hr/day operation
DEWATERED SLUDGE
20% Solids
1500 lbs
275 ton/yr
5200 gal
CHEMICALS
STORAGE AND
FEEDING EQUIPMENT
Ferric Chloride 60 lbs
Lime 135 lbs
FILTRATE
RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD
OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

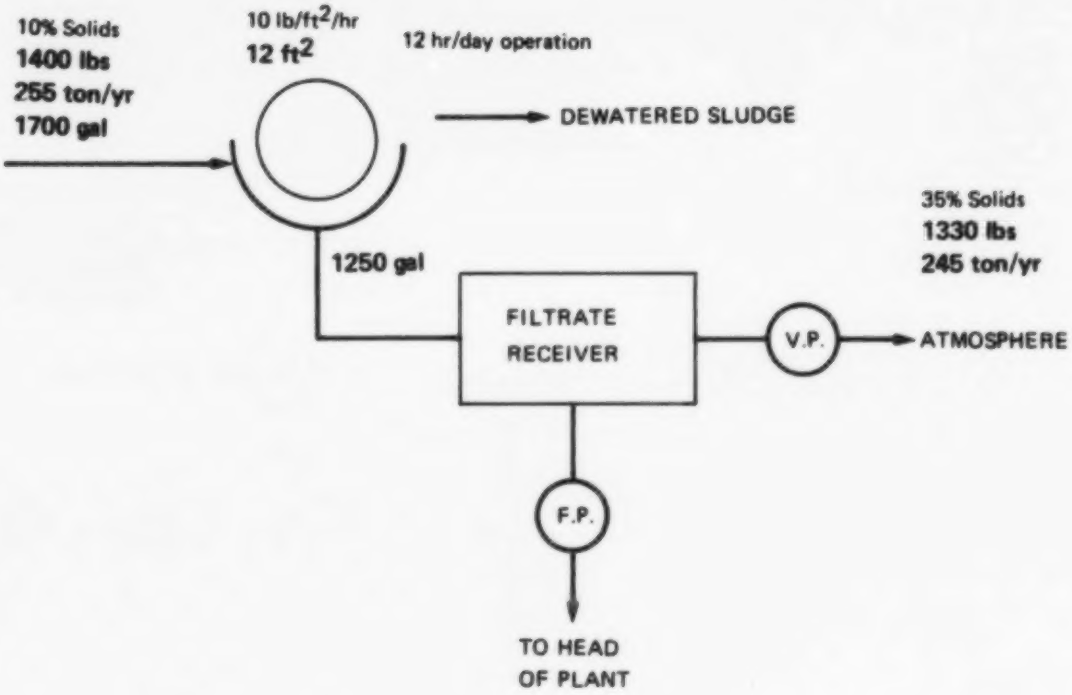
O-7. DEWATERING
Sludge Influent: Two-Stage Tertiary Lime Treatment F-1 or F-2


10% Solids
6300 lbs
1150 ton/yr
7200 gal
8 lb/ft²/hr
66 ft²
12 hr/day operation
DEWATERED SLUDGE
30% Solids
6000 lb
1100 ton/yr
4800 gal
FILTRATE RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

O-8. DEWATERING

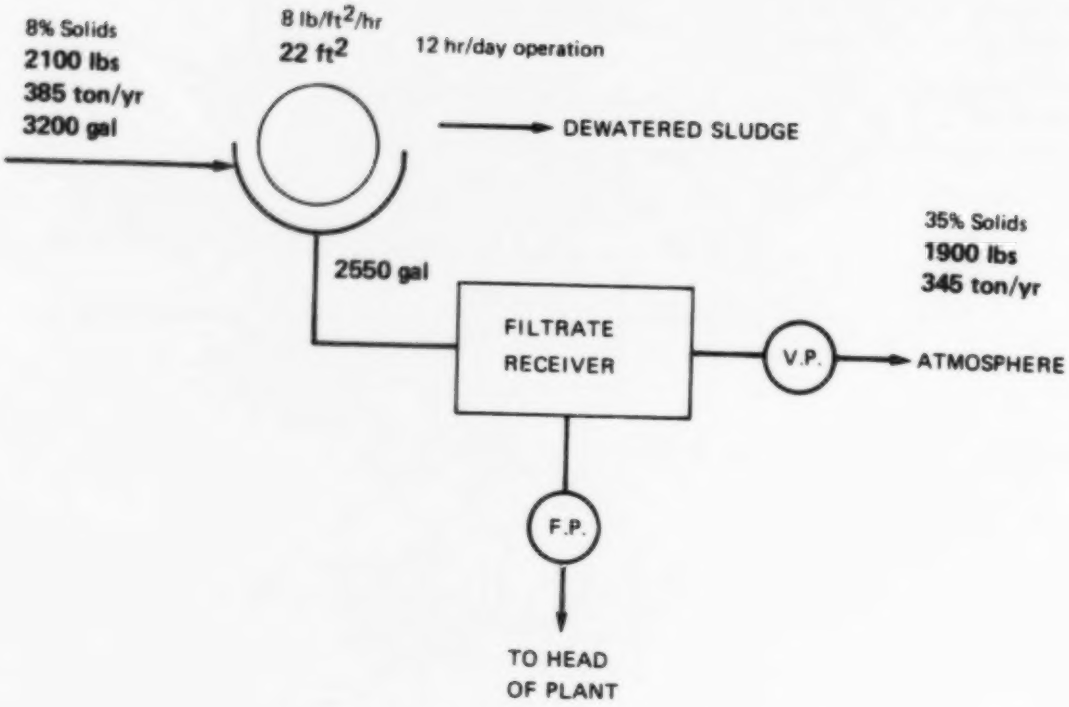
Sludge Influent: Heat-Treated Primary + Secondary – Conventional M-1


10% Solids
1400 lbs
255 ton/yr
1700 gal
10 lb/ft2/hr
12 ft2
12 hr/day operation
DEWATERED SLUDGE
35% Solids
1330 lbs
245 ton/yr
1250 gal
FILTRATE RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

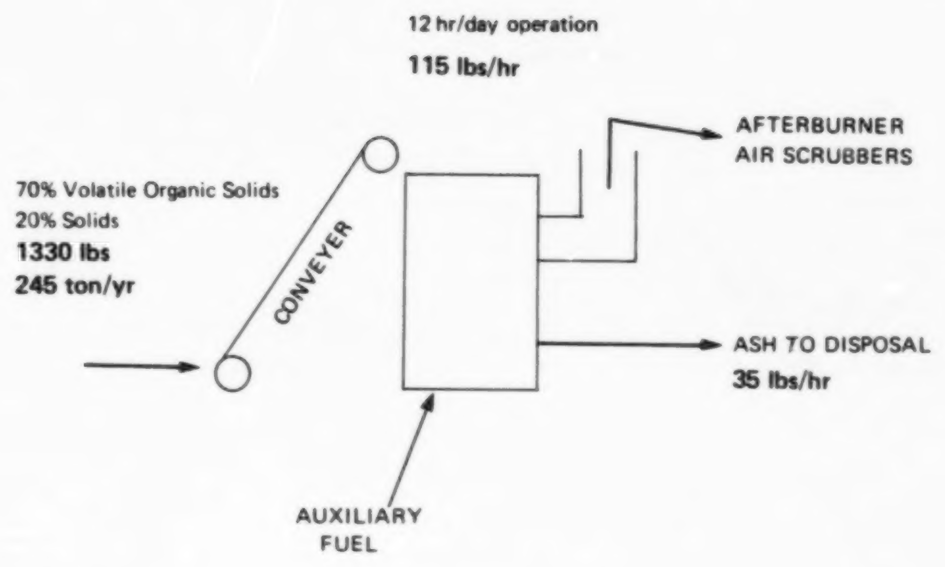
O-9. DEWATERING

Sludge Influent: Heat Treated Primary + Secondary (Alum or $FeCl_3$ Addition) M-2


8% Solids
2100 lbs
385 ton/yr
3200 gal
8 lb/ft²/hr
22 ft²
12 hr/day operation
DEWATERED SLUDGE
35% Solids
1900 lbs
345 ton/yr
2550 gal
FILTRATE RECEIVER
V.P.
ATMOSPHERE
F.P.
TO HEAD OF PLANT

Design criteria in bold type are per mgd influent wastewater flow.

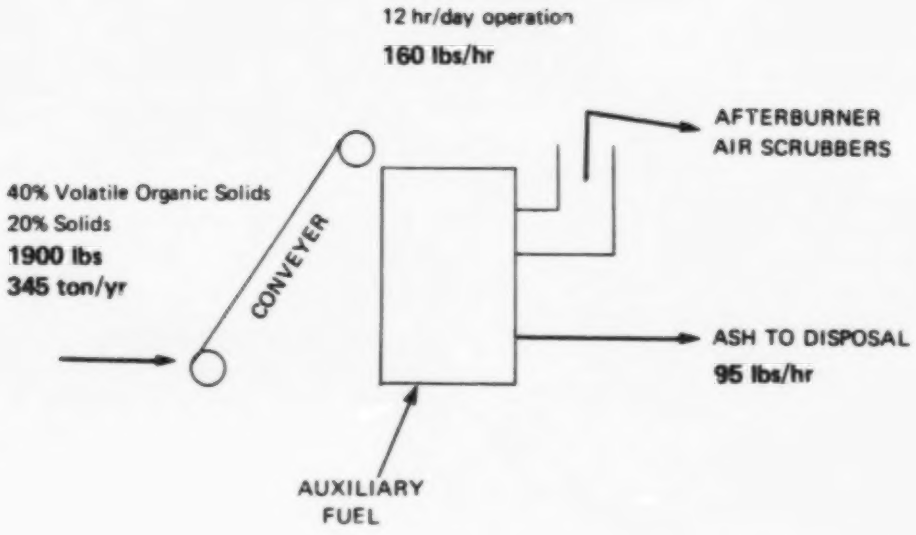
P-1. INCINERATION
Sludge Influent: Dewatered Primary + Secondary – Conventional O-1


12 hr/day operation
115 lbs/hr
AFTERBURNER
AIR SCRUBBERS
70% Volatile Organic Solids
20% Solids
1330 lbs
245 ton/yr
CONVEYER
ASH TO DISPOSAL
35 lbs/hr
AUXILIARY
FUEL

Design criteria in bold type are per mgd influent wastewater flow.

P-2. INCINERATION

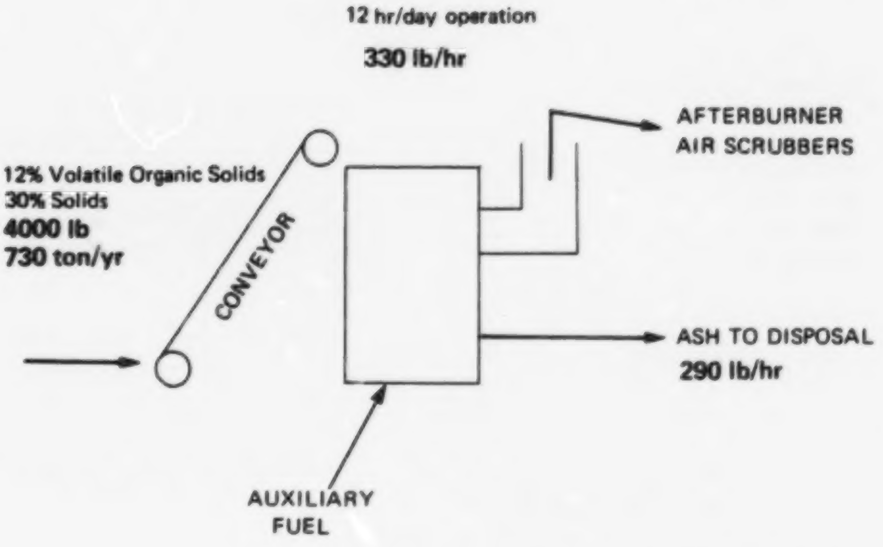
Sludge Influent: Dewatered Primary + Secondary
(Alum or $FeCl_3$ Addition) O-2


12 hr/day operation
160 lbs/hr
AFTERBURNER
AIR SCRUBBERS
40% Volatile Organic Solids
20% Solids
1900 lbs
345 ton/yr
CONVEYER
ASH TO DISPOSAL
95 lbs/hr
AUXILIARY
FUEL

Design criteria in bold type are per mgd influent wastewater flow.

P-3. INCINERATION

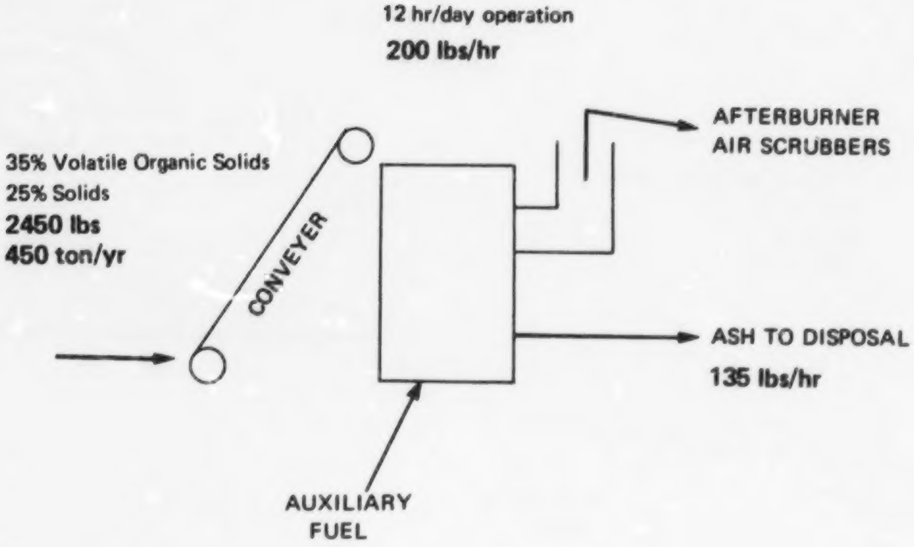
Sludge Influent: Primary Sedimentation – Two-Stage Lime Addition O-3


12 hr/day operation
330 lb/hr
AFTERBURNER
AIR SCRUBBERS
12% Volatile Organic Solids
30% Solids
4000 lb
730 ton/yr
CONVEYOR
ASH TO DISPOSAL
290 lb/hr
AUXILIARY
FUEL

Design criteria in bold type are per mgd influent wastewater flow.

P-4. INCINERATION

Sludge Influent: Dewatered Primary Sedimentation – Single Stage Lime Addition O-4

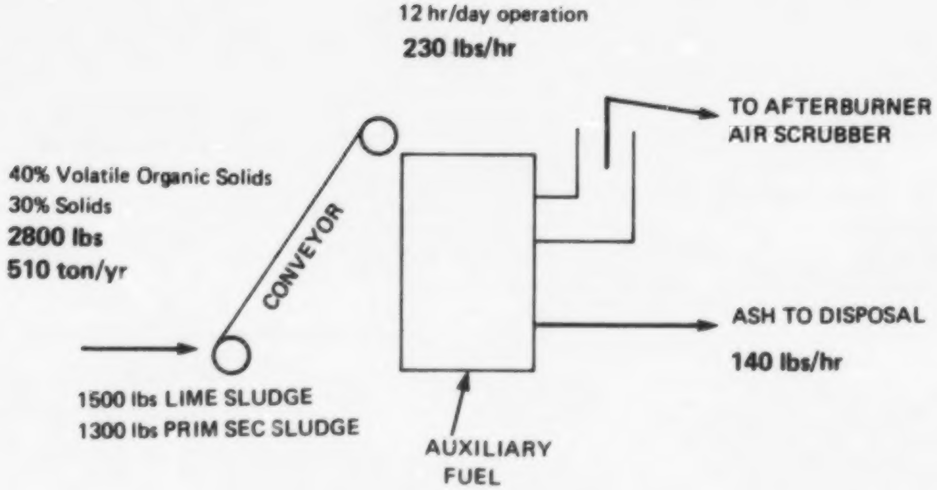

12 hr/day operation
200 lbs/hr
AFTERBURNER
AIR SCRUBBERS
35% Volatile Organic Solids
25% Solids
2450 lbs
450 ton/yr
CONVEYER
ASH TO DISPOSAL
135 lbs/hr
AUXILIARY
FUEL

Design criteria in bold type are per mgd influent wastewater flow.

P-5. INCINERATION

Sludge Influent: Dewatered Tertiary Two-Stage Lime Treated + Dewatered Primary and Secondary – Conventional

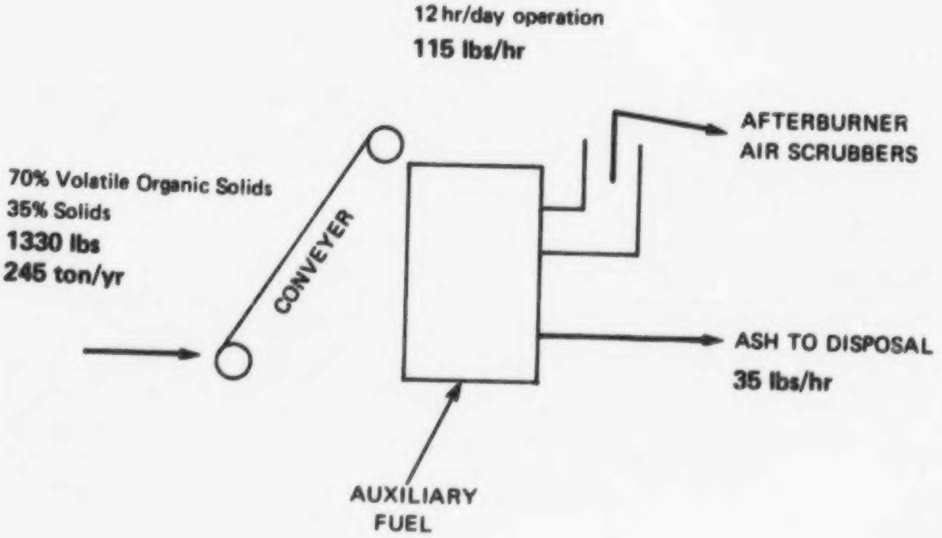
O-7 + O-1


12 hr/day operation
230 lbs/hr
TO AFTERBURNER
AIR SCRUBBER
40% Volatile Organic Solids
30% Solids
2800 lbs
510 ton/yr
CONVEYOR
ASH TO DISPOSAL
140 lbs/hr
1500 lbs LIME SLUDGE
1300 lbs PRIM SEC SLUDGE
AUXILIARY
FUEL

Design criteria in bold type are per mgd invluent wastewater flow

P-6. INCINERATION

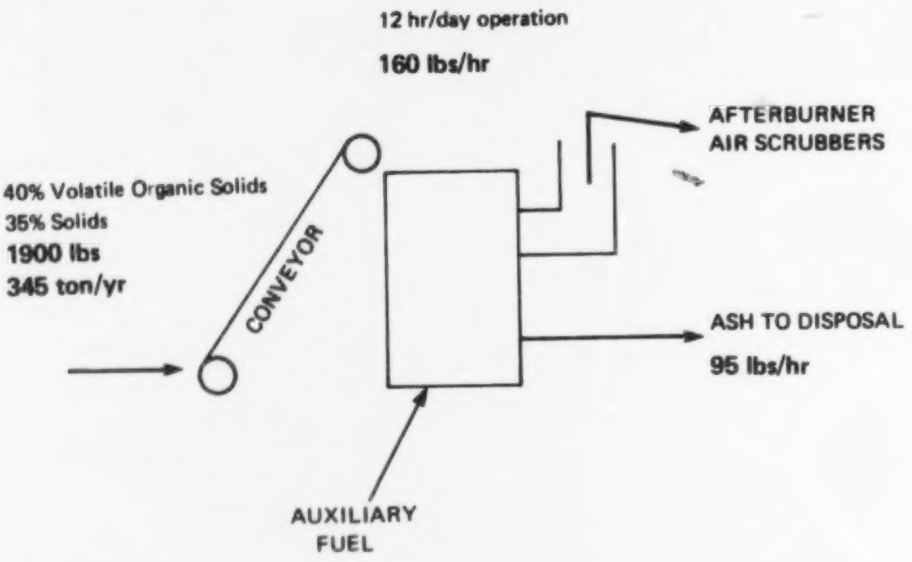
Sludge Influent: Dewatered Heat-Treated Primary + Secondary – Conventional O-8


12 hr/day operation
115 lbs/hr
70% Volatile Organic Solids
35% Solids
1330 lbs
245 ton/yr
CONVEYER
AFTERBURNER
AIR SCRUBBERS
ASH TO DISPOSAL
35 lbs/hr
AUXILIARY
FUEL

Design criteria in bold type are per mgd influent wastewater flow.

P-7. INCINERATION

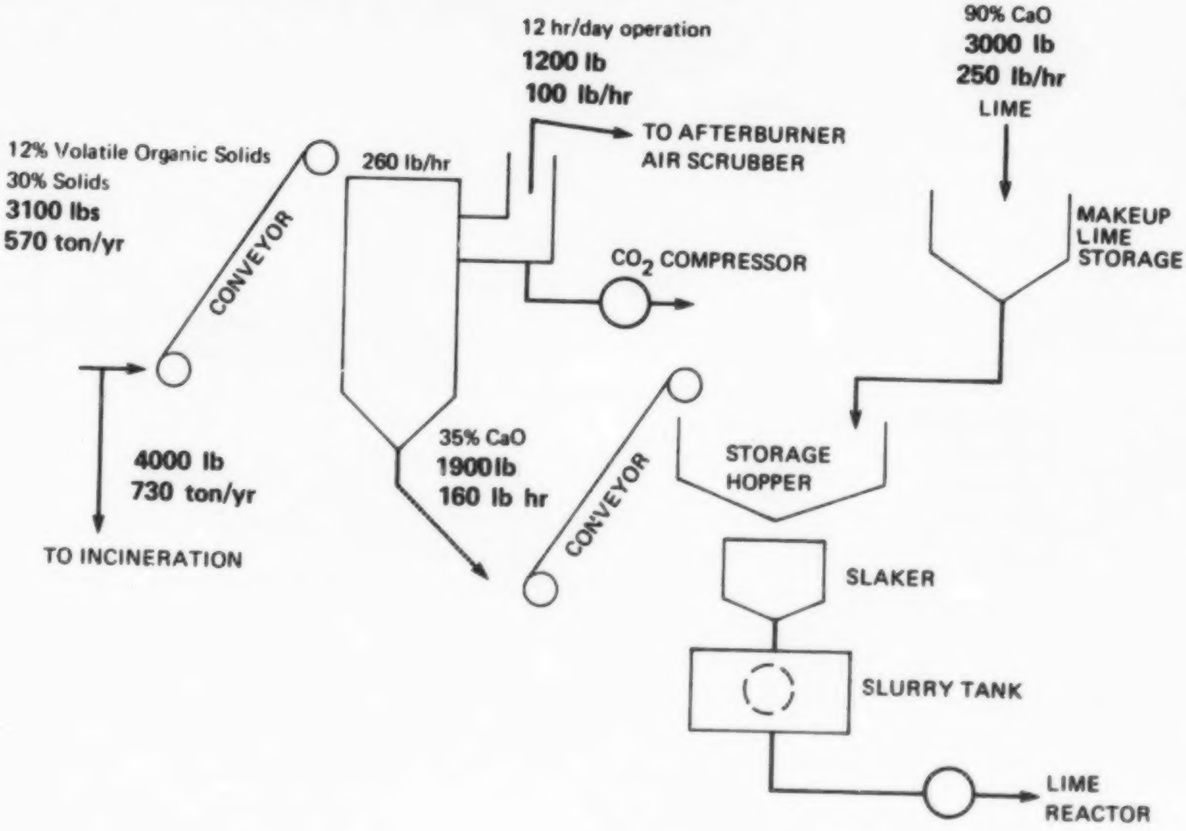
Sludge Influent: Dewatered Heat-Treated Primary + Secondary (Alum + $FeCl_3$ Addition) O-9


12 hr/day operation
160 lbs/hr
AFTERBURNER
AIR SCRUBBERS
40% Volatile Organic Solids
35% Solids
1900 lbs
345 ton/yr
CONVEYOR
ASH TO DISPOSAL
95 lbs/hr
AUXILIARY
FUEL

Design criteria in bold type are per
mgd influent wastewater flow

Q-1. RECALCINATION

Influent: **Dewatered Sludge From Two-Stage Lime Addition in Primary (O-3)**



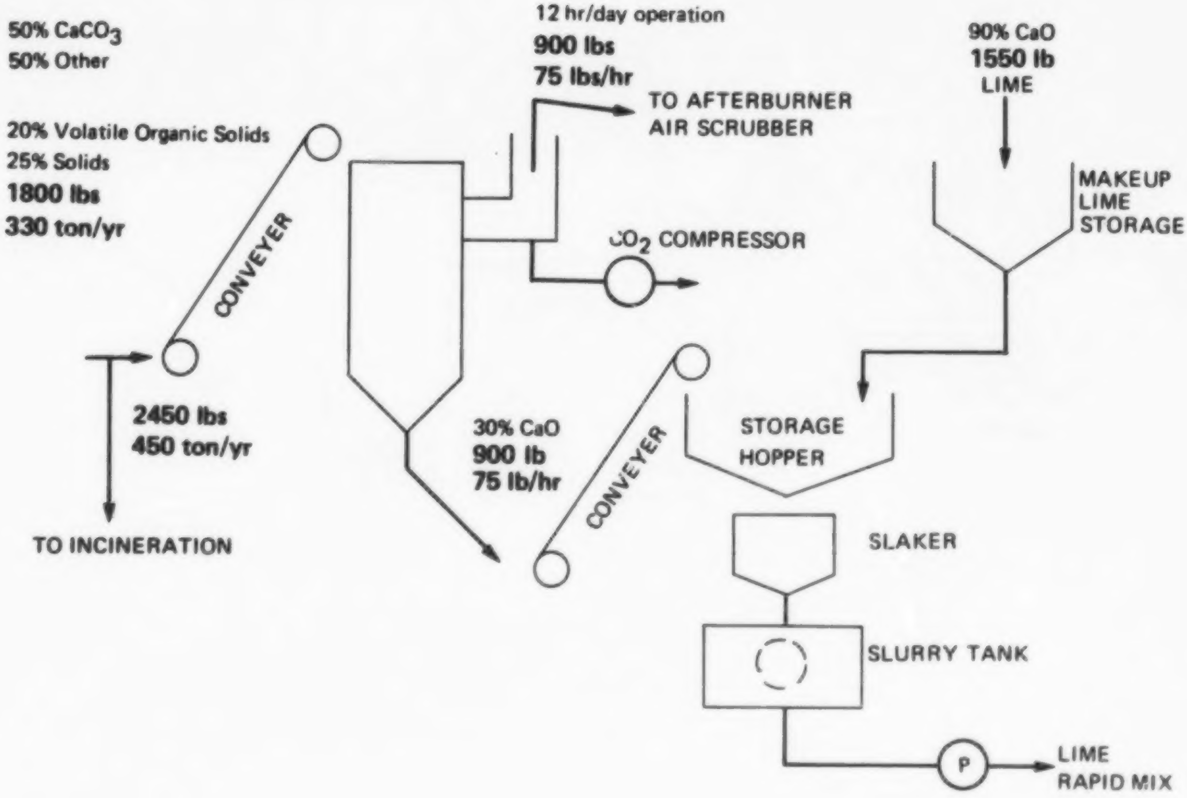
12 hr/day operation
1200 lb
100 lb/hr
TO AFTERBURNER AIR SCRUBBER
90% CaO
3000 lb
250 lb/hr
LIME
12% Volatile Organic Solids
30% Solids
3100 lbs
570 ton/yr
CONVEYOR
260 lb/hr
CO_2 COMPRESSOR
MAKEUP LIME STORAGE
4000 lb
730 ton/yr
TO INCINERATION
35% CaO
1900 lb
160 lb hr
CONVEYOR
STORAGE HOPPER
SLAKER
SLURRY TANK
LIME REACTOR

Assumptions: 60% Solids recovery in furnace
Minimum of 75% purity by weight of $Ca(OH)_2$ feed to lime rapid mix

Design criteria in bold type are per mgd influent wastewater flow

Q-2. RECALCINATION

Influent: Dewatered Sludge from Single Stage Lime Addition In Primary Sedimentation + Sludge From Secondary Treatment (O-4)

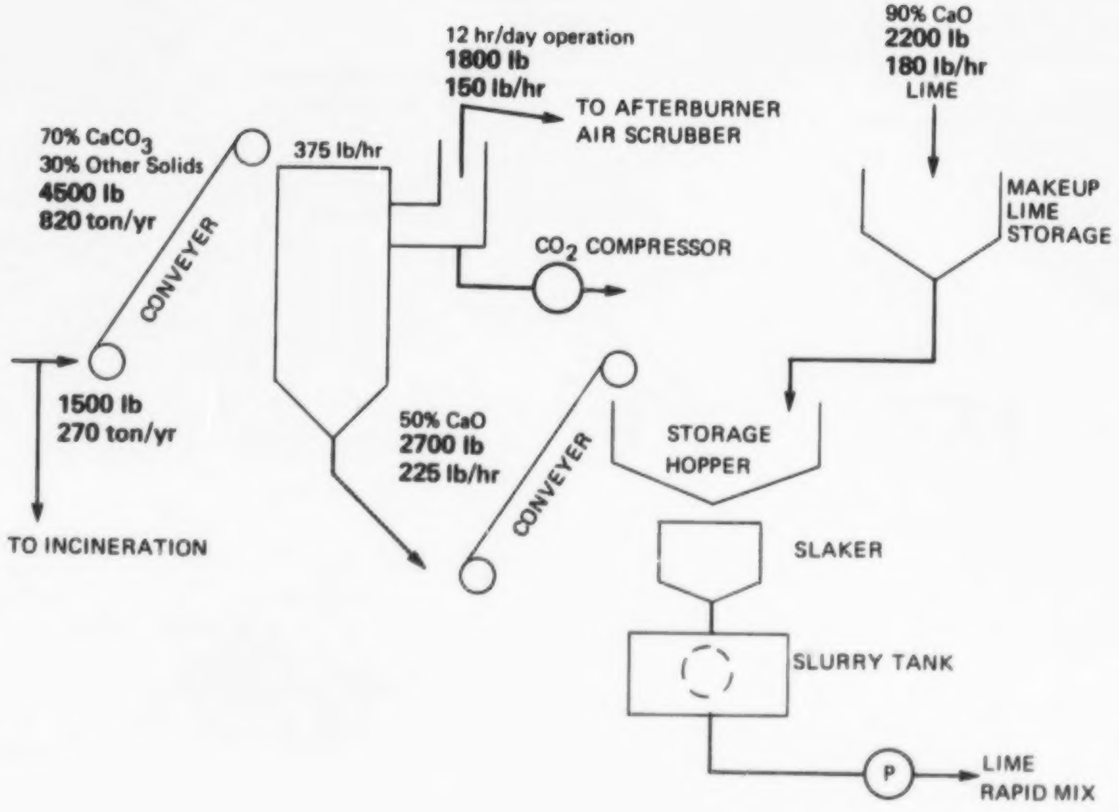

50% $CaCO_3$
50% Other
20% Volatile Organic Solids
25% Solids
1800 lbs
330 ton/yr
CONVEYER
2450 lbs
450 ton/yr
TO INCINERATION
12 hr/day operation
900 lbs
75 lbs/hr
TO AFTERBURNER
AIR SCRUBBER
CO_2 COMPRESSOR
30% CaO
900 lb
75 lb/hr
CONVEYER
90% CaO
1550 lb
LIME
MAKEUP
LIME
STORAGE
STORAGE
HOPPER
SLAKER
SLURRY TANK
P
LIME
RAPID MIX

Assumptions:
50% solids recovery in furnace
Minimum of 75% purity by weight of $Ca(OH)_2$ feed to lime rapid mix
Only lime sludge is recalcined.

Design criteria in bold type are per mgd influent wastewater flow

Q-3. RECALCINATION

Influent: Dewatered Sludge From – Two-Stage Tertiary Lime Treatment (O-7)



12 hr/day operation
1800 lb
150 lb/hr
TO AFTERBURNER
AIR SCRUBBER
90% CaO
2200 lb
180 lb/hr
LIME
70% CaCO3
30% Other Solids
4500 lb
820 ton/yr
375 lb/hr
MAKEUP
LIME
STORAGE
CONVEYER
CO2 COMPRESSOR
1500 lb
270 ton/yr
50% CaO
2700 lb
225 lb/hr
STORAGE
HOPPER
CONVEYER
TO INCINERATION
SLAKER
SLURRY TANK
P
LIME
RAPID MIX

Assumptions: **60% solids recovery in furnace**

Minimum of 75% purity be weight of $Ca(OH)_2$ feed to lime rapid mix.

Design criteria in bold type are per mgd influent wastewater flow

Section III - Costs of Unit Processes

3.1 Cost Determinations

Costs were determined for each unit process depicted in the series of flow sheets. Capital costs and operation and maintenance costs were developed based upon unit sizing as determined by standard design criteria, process loading capacities, solids generation, chemical and energy consumptions and manpower requirements. The costs generated are not intended to reflect costs for any particular region of the U.S., but are average values. Local conditions, variations in wastewater characteristics, and numerous other variables will significantly affect actual costs for specific plants. The costs presented in this report are therefore not intended as precise values but for comparing total cost of alternative wastewater treatment systems which are capable of achieving comparable effluent water quality. Detailed discussion of the use of the cost-effectiveness data is included in subsequent sections.

The sources of information utilized in obtaining cost information on the various unit processes are listed in the attached bibliography. In addition to current literature sources, important cost data were obtained from current consulting engineering design proposals for both wastewater treatment and sludge handling systems. These designs propose utilizing many of the advanced unit processes presented in this report and served as the most recent information sources for comparing cost data.

3.2 Costs Included

Total cost for each unit process comprises the sum of the capital, operating and maintenance costs. Capital costs include:

- Construction cost amortized over 20 years at 5-5/8 percent interest.
- Structures, equipment, pumps and integral piping, and appurtenances described or implied by the unit process flow sheets.
- Land requirements at $2,000 per acre.
- Engineering, contingencies, and interest during construction at 27 percent.

Operating and Maintenance costs include:

- Annual average equivalent of operating and maintenance costs including labor, taken at 100 percent utilization of each unit process within the system throughout the life of the plant.
- All material costs, including chemicals, power and fuel, and other materials.

A listing of consumable goods and associated costs considered in the unit processes are presented in Table III-1. All costs utilized are trended to a common cost level. Capital costs are trended by use of the National Average Wastewater Treatment Plant Cost Index of 177.5 for February 1973. Material costs were trended using the Wholesale Price Index for Industrial Commodities of 120.0, current for February, 1973. Labor cost, including allowance for fringe benefits, was taken at $5.00 per hour. The cost indices used were made available by the EPA and Department of Labor Statistics office.

The reader is reminded that construction and O&M costs are constantly changing and since these cost curves were formulated (February 1973), the National Average Wastewater Treatment Plant Cost Index, the Wholesale Price Index for Industrial Commodities, the labor rate, the cost of land, and the Water Resources Council interest rate have changed.

Should the reader desire to modify the cost curves presented herein by changing one or more of these assumptions, he is directed to Appendix B of this report where costs equations have been developed with a flexibility that permits changing various economic parameters, e.g. cost indices, labor rate, etc.

3.3 Costs Not Included

Costs are not included for ultimate sludge disposal, yardwork, pump stations and pipelines for conveyance of wastewater to the treatment plant, outfalls, the effect of recycle streams where judged insignificant, or for other facilities, such as garages, administration buildings and laboratories, most of which would be common to any complete wastewater treatment system. Inclusion of such common cost is not necessary since the focus of this study is primarily the comparison of alternative wastewater treatment and sludge handling systems.

3.4 Cost Curves for Unit Processes

Utilizing the sources coded in the bibliography, total annual costs were determined, including amortized capital cost and annual operation and maintenance costs for each wastewater treatment and sludge handling process. This was accomplished for influent wastewater flows of 1, 5, 20, and 100 MGD. The total annual cost, annual amortized capital cost and annual operating and maintenance cost were then converted to cost in cents per 1000 gallons of treated influent wastewater, and cost curves were plotted from 1 to 100 MGD for each process considered. These curves follow at the end of this section.

For reasons discussed in the preceding section, there are several flow sheets associated with each unit process. For a given unit process, each flow sheet defines specific operating conditions inherent to the flow sheet. The conditions specified are sufficiently different to change capital and/or operating and maintenance costs from those of a similar flow sheet defining the given unit process under other specific operating conditions. Thus, three curves, one for total cost, one for operating and maintenance costs, and one for amortized capital cost have been developed for each flow sheet in Section II.
Each flow sheet and its companion cost curves bear the same identification number and title.

3.5 Factors other than Cost Considered in Selecting Wastewater Treatment Unit Processes

There are other factors which must be considered in the final selection of appropriate unit processes for wastewater treatment and sludge handling. These factors are assessed qualitatively in Table III -2.

3.6 Calculation of Capital Cost, O&M Cost, and Total Cost

For example's sake only, the capital cost (in dollars), O&M cost (in dollars/yr) and total cost (in dollars/yr) for a 20 MGD conventional primary sedimentation facility (unit process A-1) are calculated below.

Before embarking on similar calculations, the user of this guide should realize that its purpose is to make comparative cost analyses of alternative treatment systems. These calculations are provided for the convenience of those who wish to use the information contained herein as rough approximations of capital and O&M costs. Extreme caution should be exercised in using data in this manner because (1) many costs have not been considered (See Section 3.3. Costs Not included), (2) there are wide cost variations caused by factors unique to any given project, e.g., site conditions, local variations in material and labor costs and different wastewater characteristics, and (3) cost curves were developed with cost indices, interest rate, and manhour labor rate current for February 1973. (Refer to Section III - 2.) The reader should obtain current cost indices, labor rate, and interest rate and utilize the cost equations in Appendix B for more current information.

CAPITAL COST

$$\begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\\ \text{from curve}^1\end{pmatrix}, \frac{¢}{1000\text{ gal}} \times \frac{Q, 10^6\text{ gal}}{\text{day}} \times \frac{\$}{100¢} \times \frac{365\text{ days}}{\text{yr}} = \begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\end{pmatrix}, \frac{\$}{\text{yr}}$$

$$\begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\\ \text{from curve}^1\end{pmatrix} \times 3650\,Q = \begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\end{pmatrix}, \$/\text{yr}$$

$$\begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\end{pmatrix}, \frac{\$}{\text{yr}} \times \text{PWF }(5\ 5/8\%,\ 20\text{ yrs})^2 = \text{Capital Cost, }\$$$

Substituting 11.83 for PWF and summarizing,

$$\begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\\ \text{from curve}\end{pmatrix} \times 43179.5\,Q = \text{Capital Cost, }\$$$

Substituting 20 MGD for Q and 0.8¢/1000 gal for $\begin{pmatrix}\text{Amortized}\\ \text{Capital Cost}\\ \text{from curve}\end{pmatrix}$,

Capital Cost = $690,000

---

1 Although this example uses a value from the capital cost curve for unit process A-1, the reader should calculate the capital cost by using Appendix B equations with current indices, interest rate, and land cost for a more current estimate.

2 PWF, present worth factor, is the inverse of the capital recovery factor used in Appendix B of this guide. For a 20 year amortization period, some present worth factors are:

% interest	PWF
5 5/8	11.83
5 7/8	11.59
6 1/8	11.35
6 3/8	11.13

O & M COST

$$\begin{pmatrix}\text{O \& M Cost}\\ \text{from curve [3]}\end{pmatrix} \frac{¢}{1000 \text{ gal}} \times Q, \frac{10^6 \text{ gal}}{\text{day}} \times \frac{\$}{100\ ¢} \times \frac{365 \text{ days}}{\text{yr}} = \text{O\&M Cost, \$/yr}$$

$$\begin{pmatrix}\text{O \& M Cost}\\ \text{from curve [3]}\end{pmatrix} \times 3650\ Q = \text{O \& M Cost, \$/yr}$$

Substituting 20 MGD for Q and 0.5 ¢/1000 gal for $\begin{pmatrix}\text{O\&M Cost}\\ \text{from curve}\end{pmatrix}$

O & M Cost = \$36500/yr

---

[3] Although this example uses a value from the O&M cost curve for unit process A-1, the reader should calculate the O&M cost by using Appendix B equations with current indices and labor rate for a more current estimate.

TOTAL COST

Total cost, \$/yr is obtained similarly to O&M Cost, \$/yr

$$\text{Total cost, \$/yr} = \begin{pmatrix}\text{Total Cost} \\ \text{from curve}\end{pmatrix} \times 3650\,Q$$

Substituting 20 for Q and 1.3 for $\begin{pmatrix}\text{Total Cost} \\ \text{from curve}\end{pmatrix}$

Total Cost = \$94,900/yr

An alternative method[4] of calculating the total cost is to sum the amortized capital cost and O&M costs:

Total Cost = \$58,400/yr + \$36,500/yr = \$94,900/yr

---

[4] This method should be employed when Appendix B equations are used to calculate capital and O&M costs.

TABLE III-1

PROPERTIES & COSTS OF COMMON WASTE TREATMENT CHEMICALS & COSTS OF ENERGY

Chemical Name Formula Trade Name	Form As Shipped	Commercial Strength	Bulk Density Lbs/Cu Ft	Market Price F.O.B. Plant
Aluminum Sulfate	Bags	17% Al_2O_3 min.	62 - 67	$67.25/ton
$Al_2(SO_4)_3 \cdot 14\ H_2O$	Bulk	17% Al_2O_3 min.	62 - 67	$62.80/ton
Alum	Liquid	8.3% Ai_2O_3	—	$49.15/ton
Calcium Oxide	Bulk	93-98% CaO	55 - 60	$18.00-$19.50/ton
CaO	Bags			$23.00-$25.00/ton
Quicklime				
Calcium Hydroxide	Bulk	72 - 74%	25 - 35	$19.50-$21.75/ton
$Ca(OH)_2$	Bags	as CaO		$25.00-$25.25/ton
Hydrated Lime				
Ferric Chloride	Liquid	Sewage Grade	—	$4.00/100 lbs
$FeCl_3$				
Calcium Hypochlorite	Drums	70% available	50 - 53	$29.80/100 lbs
$Ca(OCl)_2 \cdot 4\ H_2O$		Chlorine		
Chlorine	Tank Cars	—	—	$3.75/100 lbs
Cl_2	One Ton Cylinders			$7.00/100 lbs
Methanol	Tanks	100%	—	$0.12/gal.
#2 Fuel Oil				$0.65/million Btu
Natural Gas				$0.80/million Btu
Electricity				$0.015/KWH

TABLE III-2 FACTORS OTHER THAN COSTS NORMALLY CONSIDERED N SELECTION OF WASTEWATER TREATMENT AND SLUDGE HANDLING UNIT PROCESSES

	Land Requirements	Adverse Climatic Conditions	Ability to Handle Inlet Flow Variations	Ability to Handle Influent Quality Variations	Industrial Pollutants Affecting Process	Reliability of the Process	Ease of Operation & Maintenance	Occupational Hazards	Air Pollution	Waste Products
AA-Preliminary Treatment	Min.	-	Good	Good	Min.	Very Good	Fair	Structures Mech.	Odors	Grit Screenings
AB-Pumping	Min.	Freezing	Good	Good	Min.	Very Good	Fair	Structures Mech.	-	-
A-Primary Sedimentation										
Conventional	Mod.	-	Fair	Good	Mod.	Good	Very Good	Structures	Odors	Sludges
With Chemicals	Min.	-	Good	Very Good	Max.	Very Good	Good	Chemicals	-	Sludges
B-Trickling Filters	Max.	Freezing	Good	Fair	Mod.	Very Good	Very Good	Structures	Odors	Sludges
C-Activated Sludge										
Conventional	Mod.	-	Fair	Good	Mod.	Good	Fair	Structures		Sludges
With Chemicals	Min.	-	Good	Very Good	Max.	Good	Good	Chemicals		Sludges
D-Dual Media Filters	Mod.	-	Good	Good	Min.	Very Good	Good	Structures Mech.		Backwash Waste
E-Activated Carbon	Mod.	-	Good	Fair	Max.	Good	Good	Fires Explosion	Regenerant Gas	Spent Carbon
F-Two-Stage Lime Treatment	Max.	-	Good	Good	Min.	Very Good	Fair	Chemicals		Excess Sludge
G-Biological Nitrification	Max.	Cold	Fair	Fair	Mod.	Fair	Fair	Structures		Sludge
H-Biological Denitrification	Max.	Cold	Fair	Fair	Mod.	Fair	Fair	Chemical Explosions		Sludge
I-Ion Exchange	Min.	-	Fair	Good	Max.	Good	Good	Chemicals	Odor NH3	Waste Regenerant
J-Breakpoint Chlorination	Mod.	-	Good	Good	Max.	Very Good	Good	Chemicals	Chlorine Odor	*
K-Ammonia Stripping	Mod.	Cold	Fair	Fair	Min.	Good	Fair	Structures	Ammonia	Ammonia
L-Anaerobic Digestion	Max.	-	Good	Good	Max.	Good	Good	Explosion	-	Sludge CO_2 Methane
M-Heat Treatment	Mod.	-	Fair	Fair	Min.	Good	Fair	Explosion Gas	Odors	Sludge Filtrate
N-Air Drying	Max.	High Rainfall	Good	Good	Min.	Fair	Very Good	-	Odors	Sludge
O-Dewatering	Min.	-	Fair	Fair	Min.	Good	Good	Chemicals		Sludge Filtrate
P-Incineration	Min.	-	Fair	Good	Min.	Very Good	Fair	Explosions	Combustion Products	Ash
R-Disinfection	Min.	-	Good	Good	Max.	Very Good	Good	Chemicals	Chlorine Odor	*

* Increases effluent total dissolved solids

WASTEWATER TREATMENT PROCESSES

COST CURVES

		Page
Preliminary Treatment	AA	III-12
Pumping	AB	III-13
Primary Sedimentation	A-1 thru A-5	III-14 thru III-18
Trickling Filter	B-1 thru B-3	III-19 thru III-21
Activated Sludge	C-1 thru C-8	III-22 thru III-29
Filtration	D	III-30
Activated Carbon	E	III-31
Two Stage Tertiary Lime	F-1 thru F-2	III-31A thru III-32
Biological Nitrification	G-1 thru G-4	III-33 thru III-36
Biological Denitrification	H	III-37
Ion Exchange	I	III-38
Breakpoint Chlorination	J	III-39
Ammonia Stripping	K	III-40
Disinfection	R	III-41

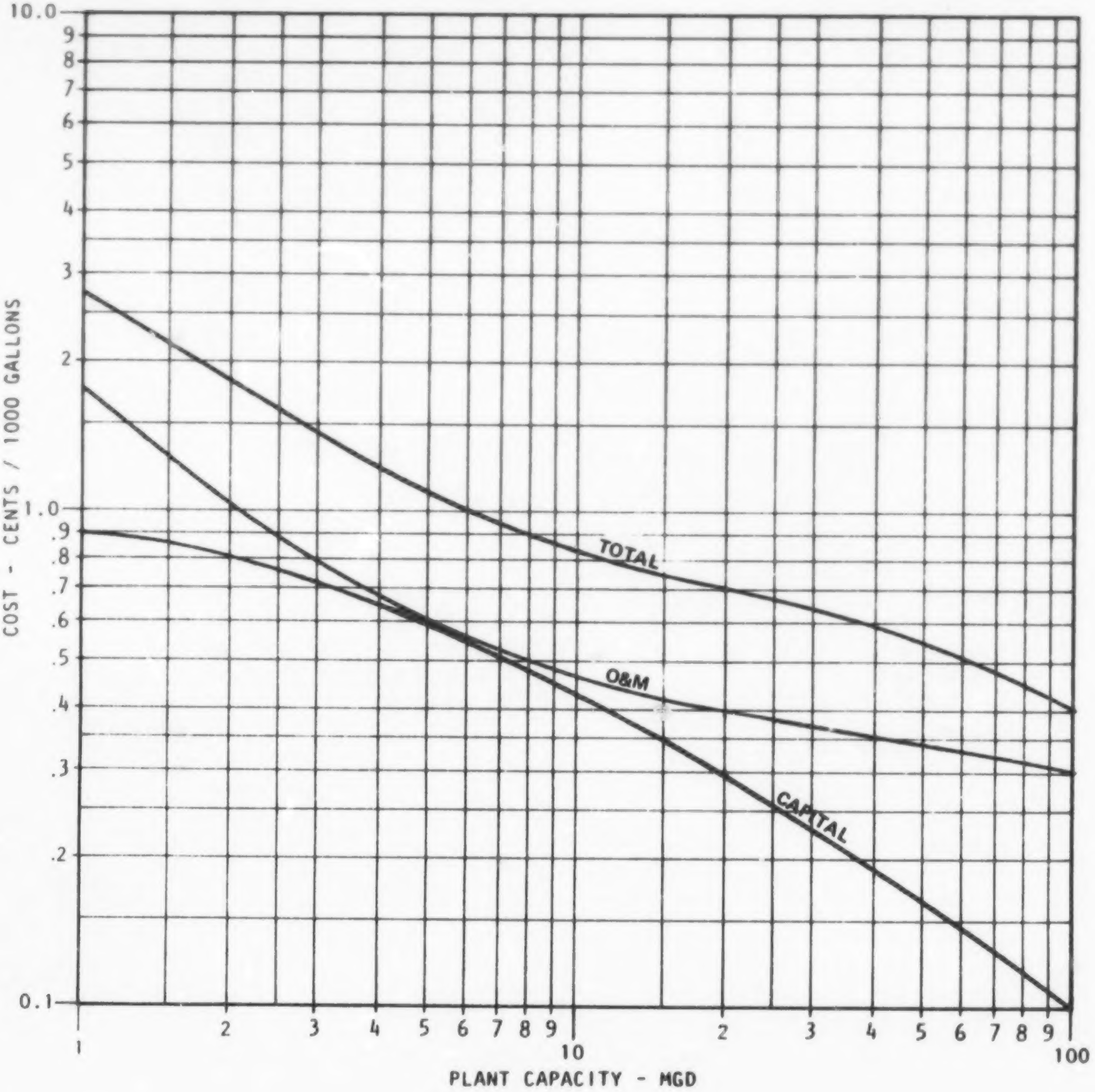
SLUDGE HANDLING PROCESSES

COST CURVES

Anaerobic Digestion	L-1 & L-2	III-42 thru III-43
Heat Treatment	M-1 & M-2	III-44 thru III-45
Air Drying	N-1 & N-2	III-46 thru III-47
Dewatering	0-1 thru 0-9	III-48 thru III-56
Incineration	P-1 thru P-7	III-57 thru III-63
Recalcination	Q-1 thru Q-3	III-64 thru III-66

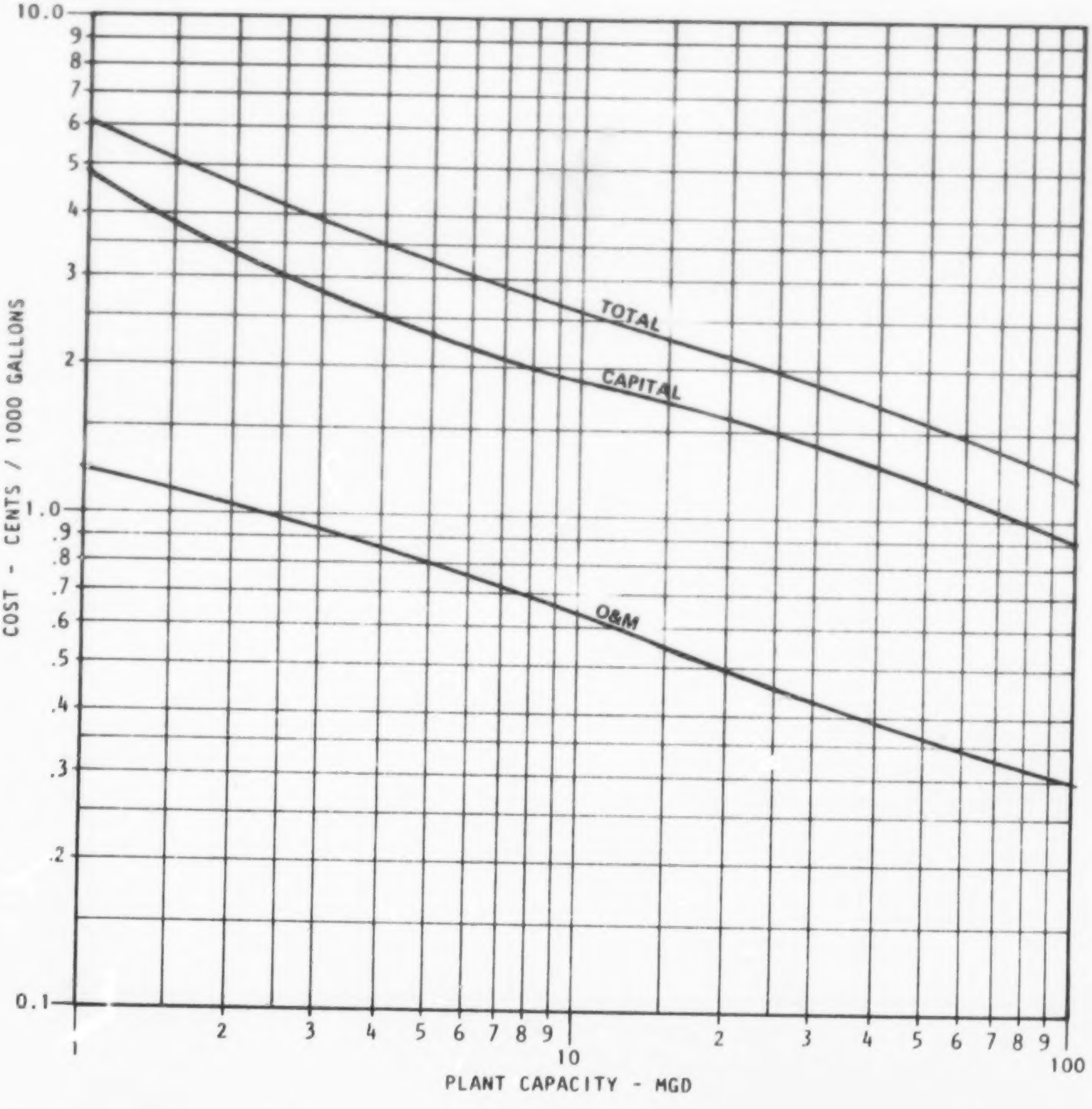
AA. PRELIMINARY TREATMENT

Influent: Raw Wastewater



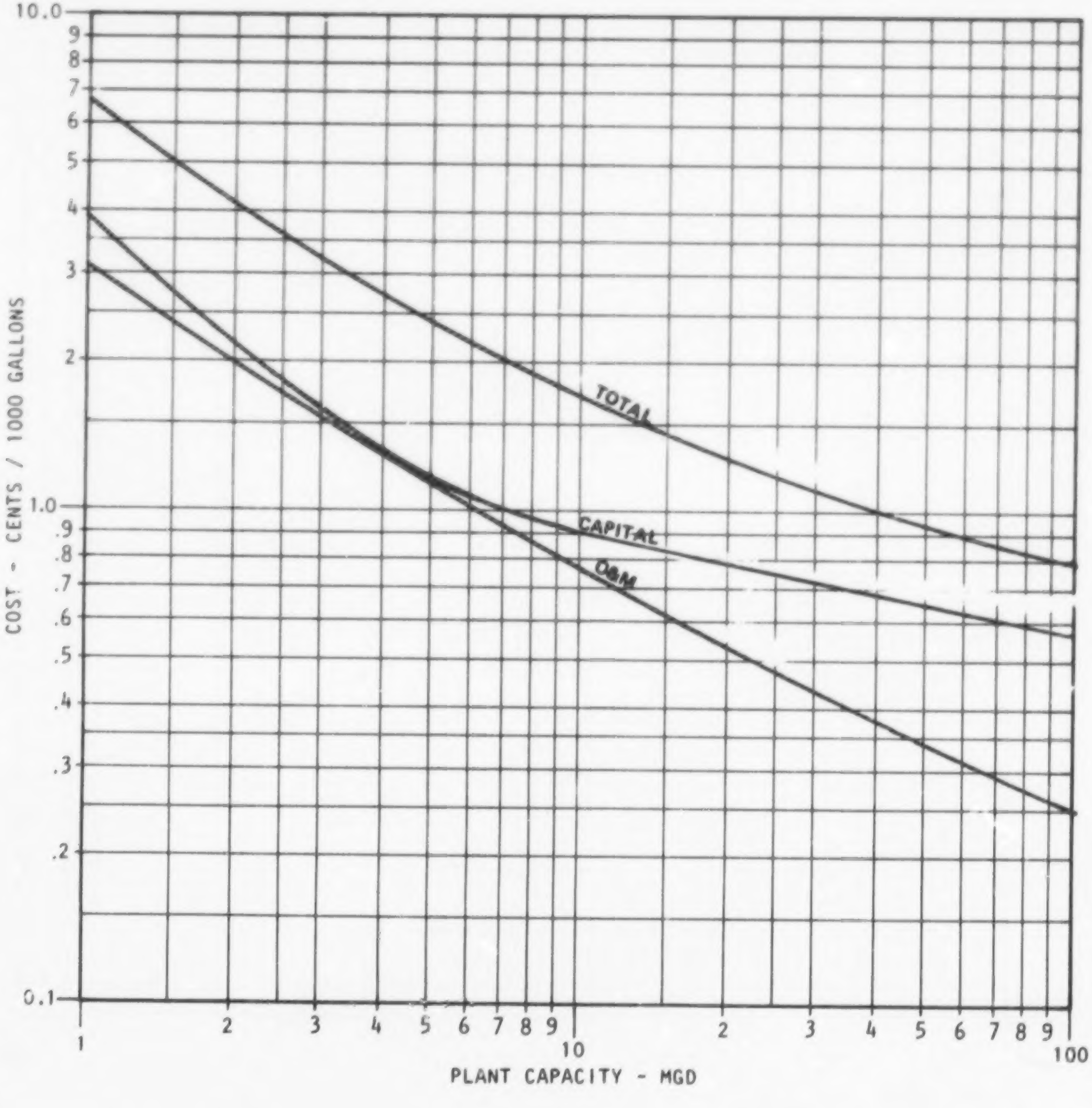
AB. RAW WASTEWATER PUMPING

Influent: Effluent from Preliminary Treatment AA



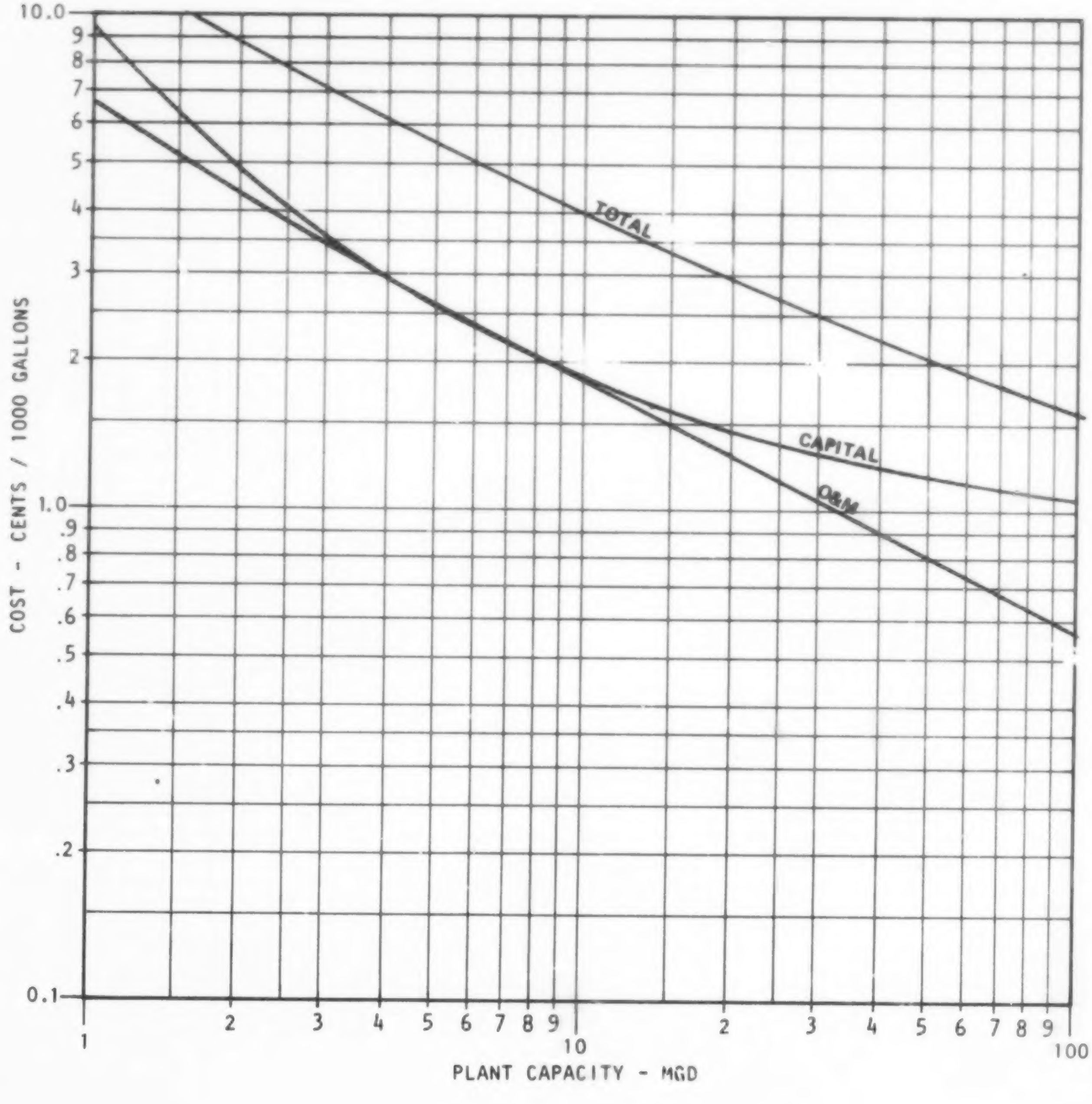
A-1. PRIMARY SEDIMENTATION – CONVENTIONAL

Influent: Effluent from Preliminary Treatment AA or
Raw Wastewater Pumping AB



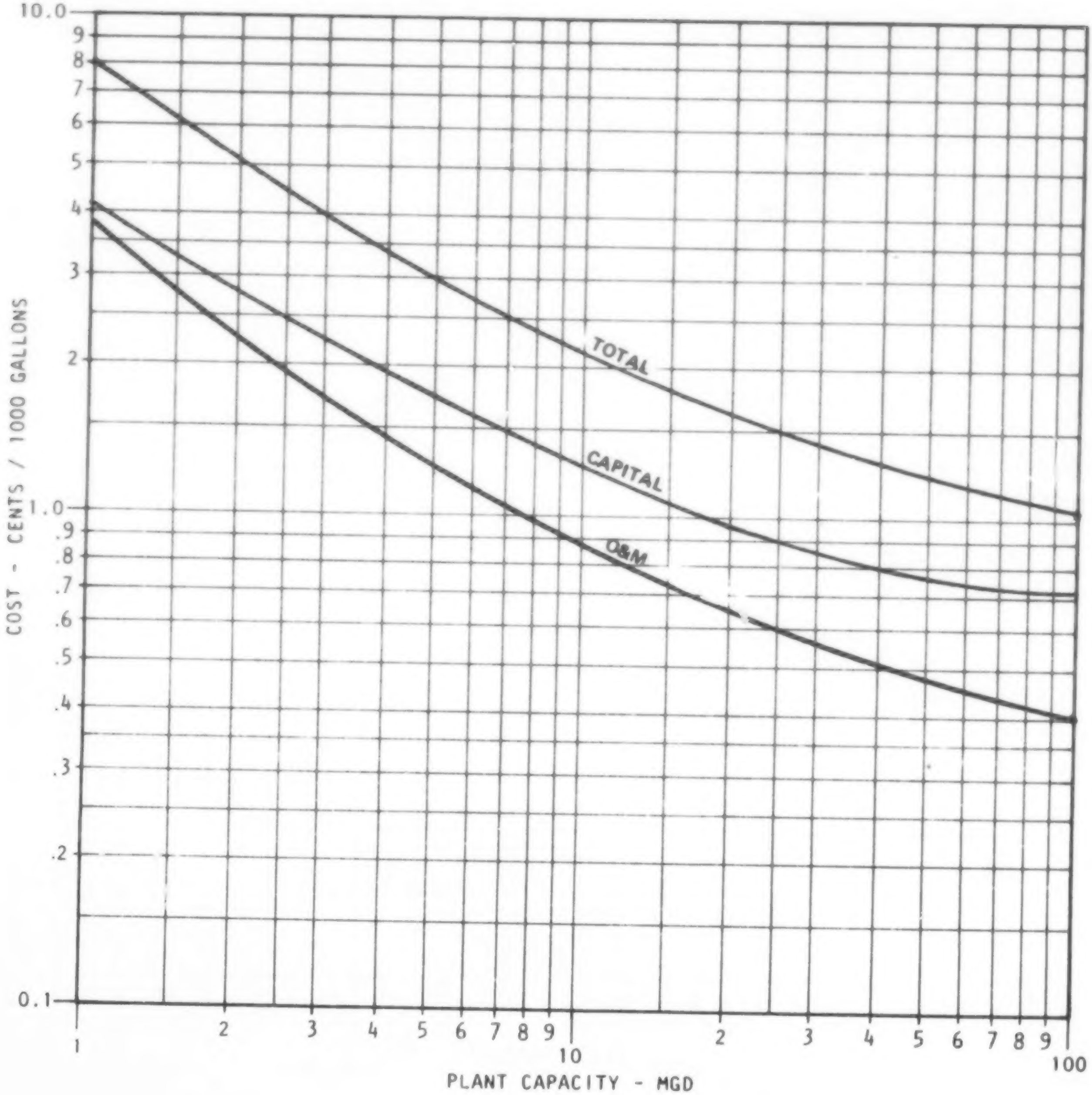
A-2. PRIMARY SEDIMENTATION – TWO-STAGE LIME ADDITION

Influent: Effluent from Preliminary Treatment AA or
Raw Wastewater Pumping AB



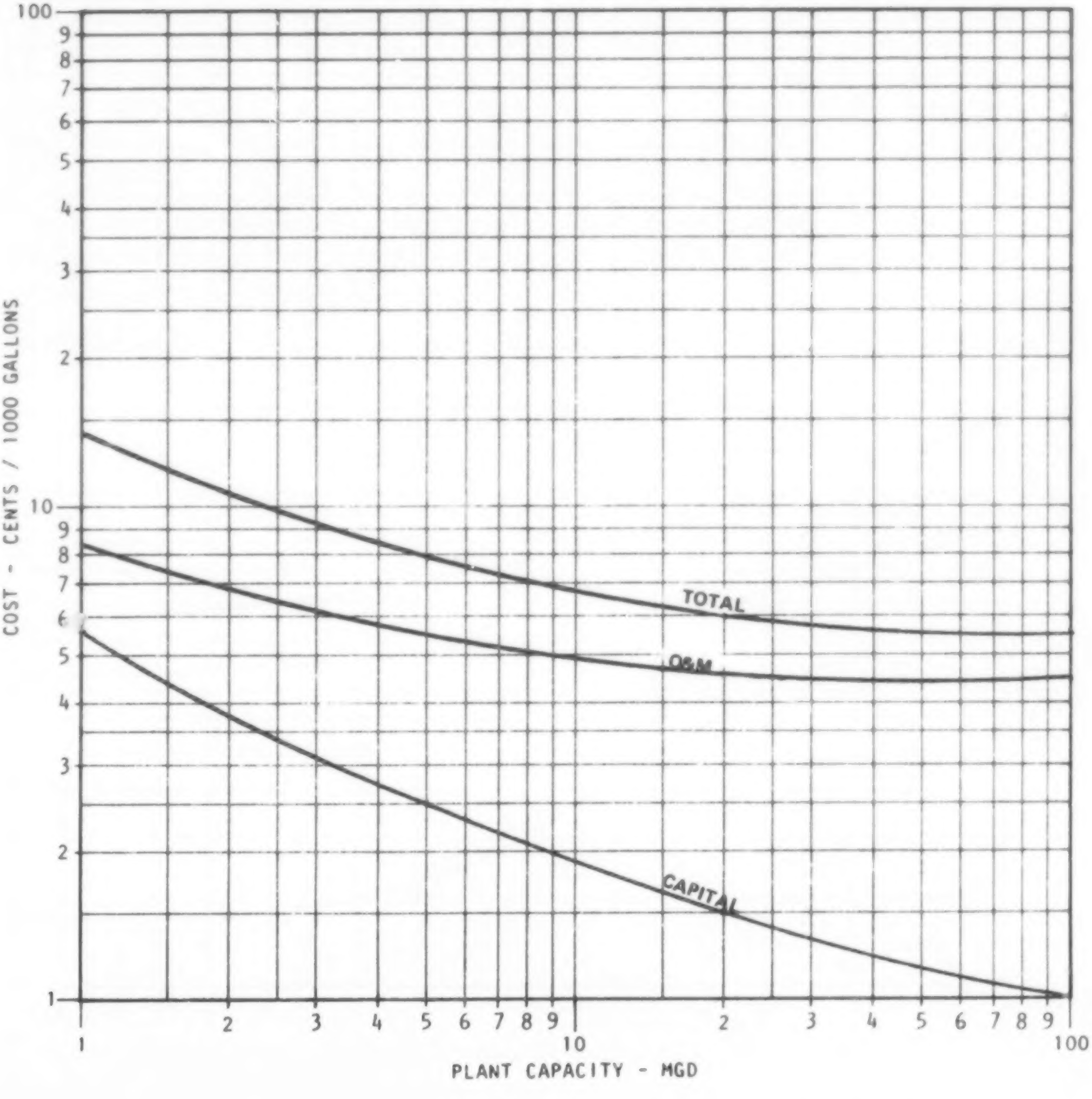
A-3. PRIMARY SEDIMENTATION – SINGLE-STAGE LIME ADDITION

Influent: Effluent from Preliminary Treatment AA or
Raw Wastewater Pumping AB



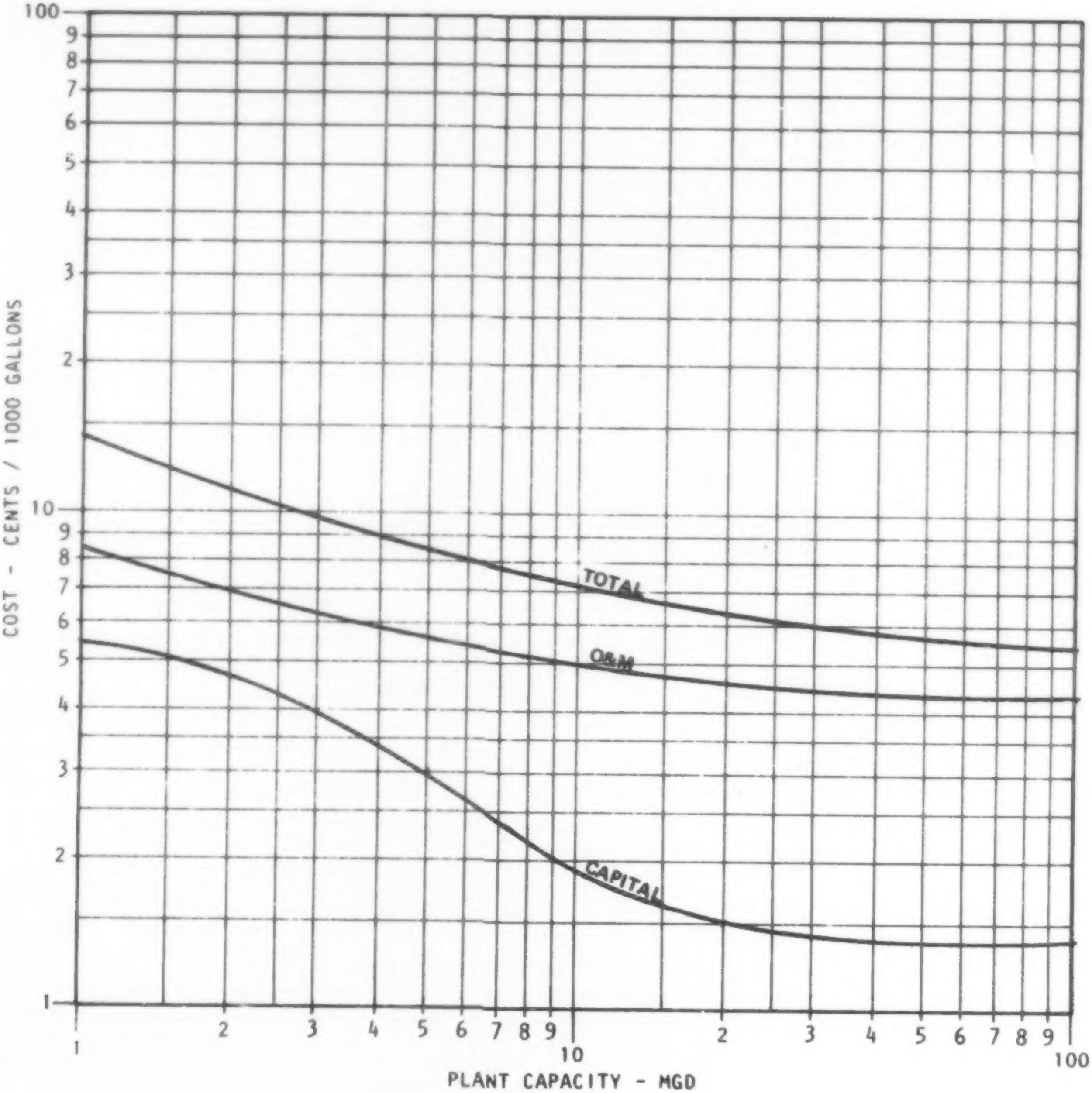
A-4. PRIMARY SEDIMENTATION – ALUM ADDITION

Influent: Effluent from Preliminary Treatment AA or
Raw Wastewater Pumping AB

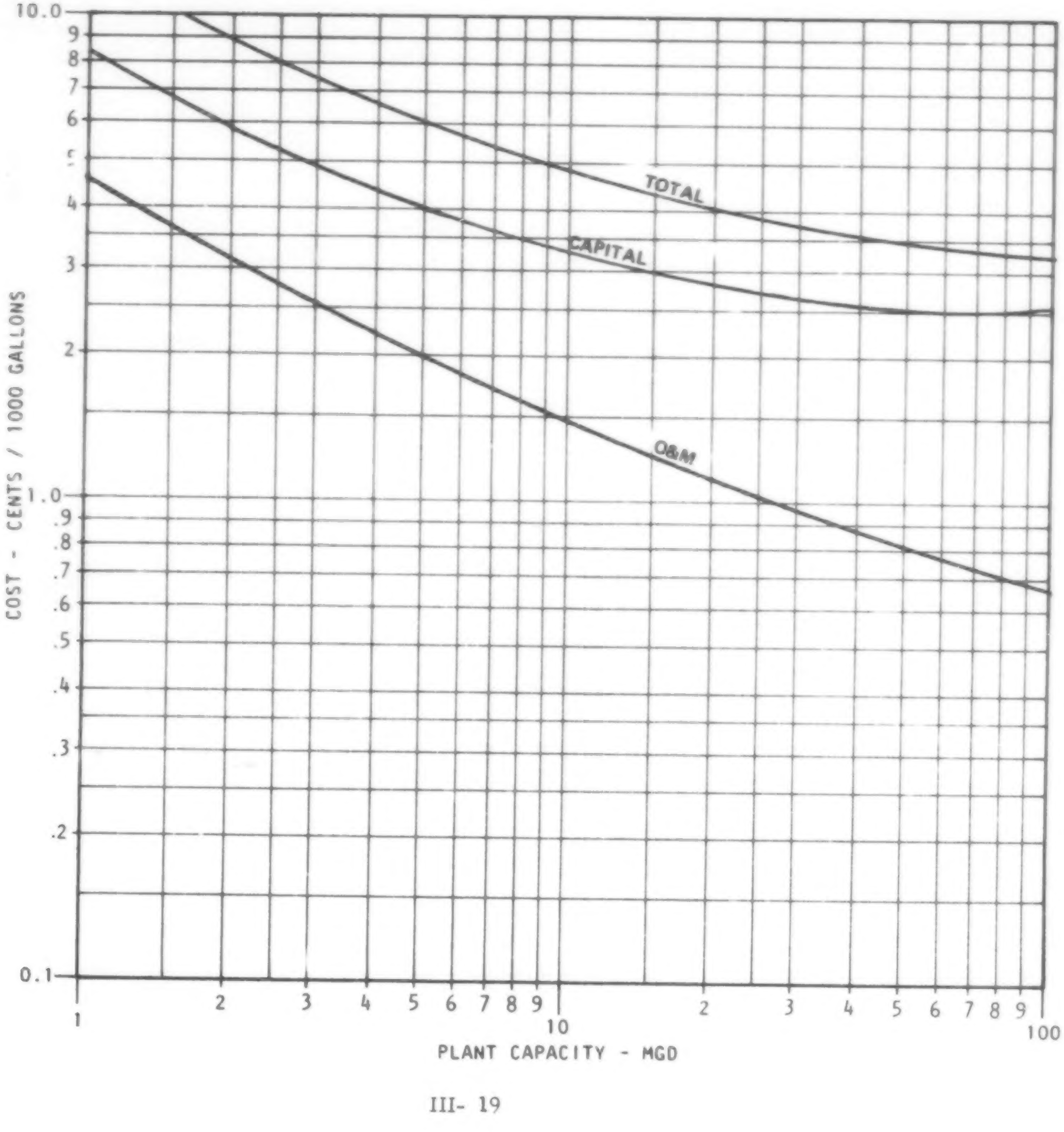


A-5. PRIMARY SEDIMENTATION – $FeCl_3$ ADDITION

Influent: Effluent from Preliminary Treatment AA or
Raw Wastewater Pumping AB

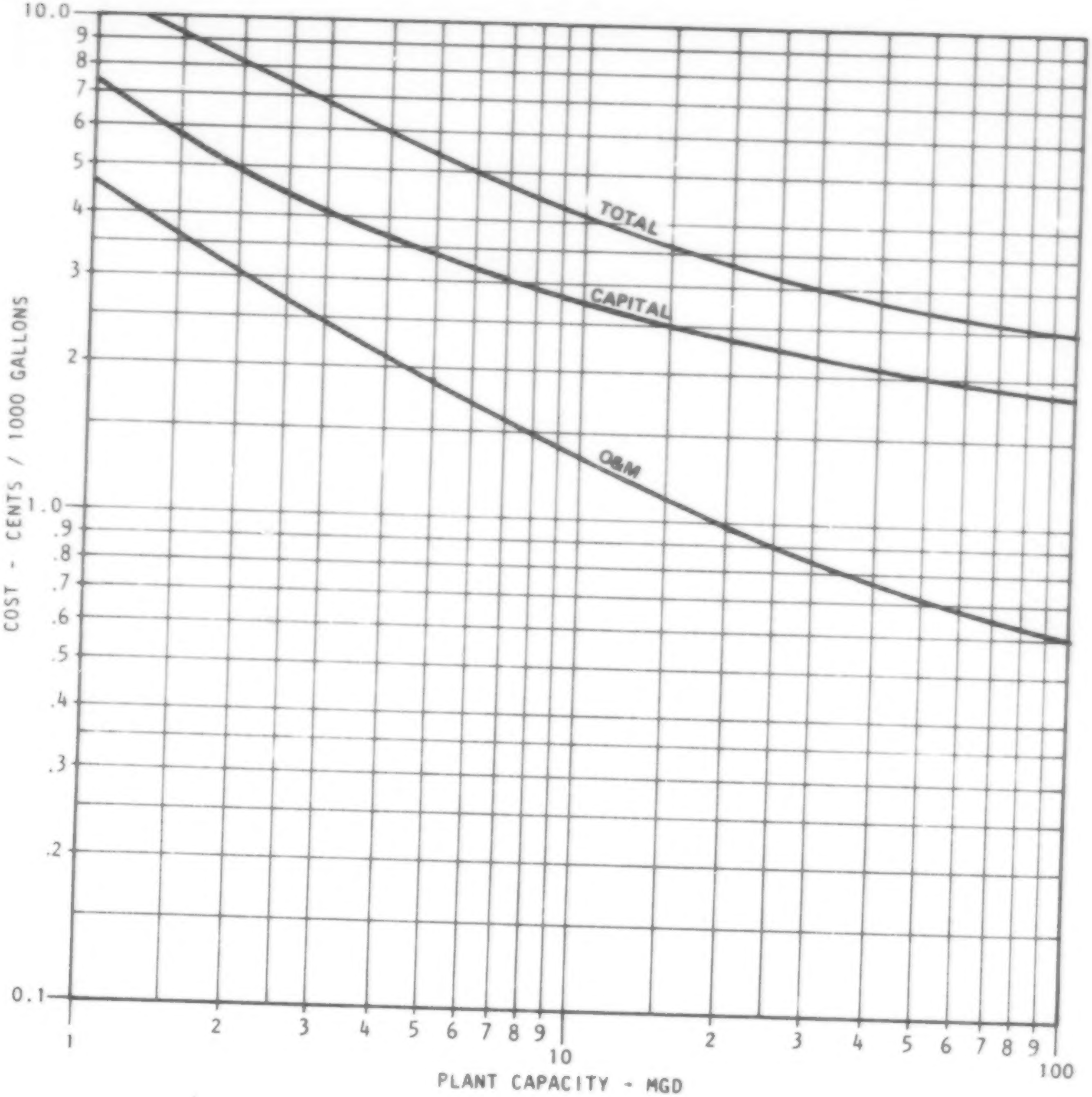


B-1. TRICKLING FILTER
Influent: Effluent From Primary Sedimentation – Conventional A-1

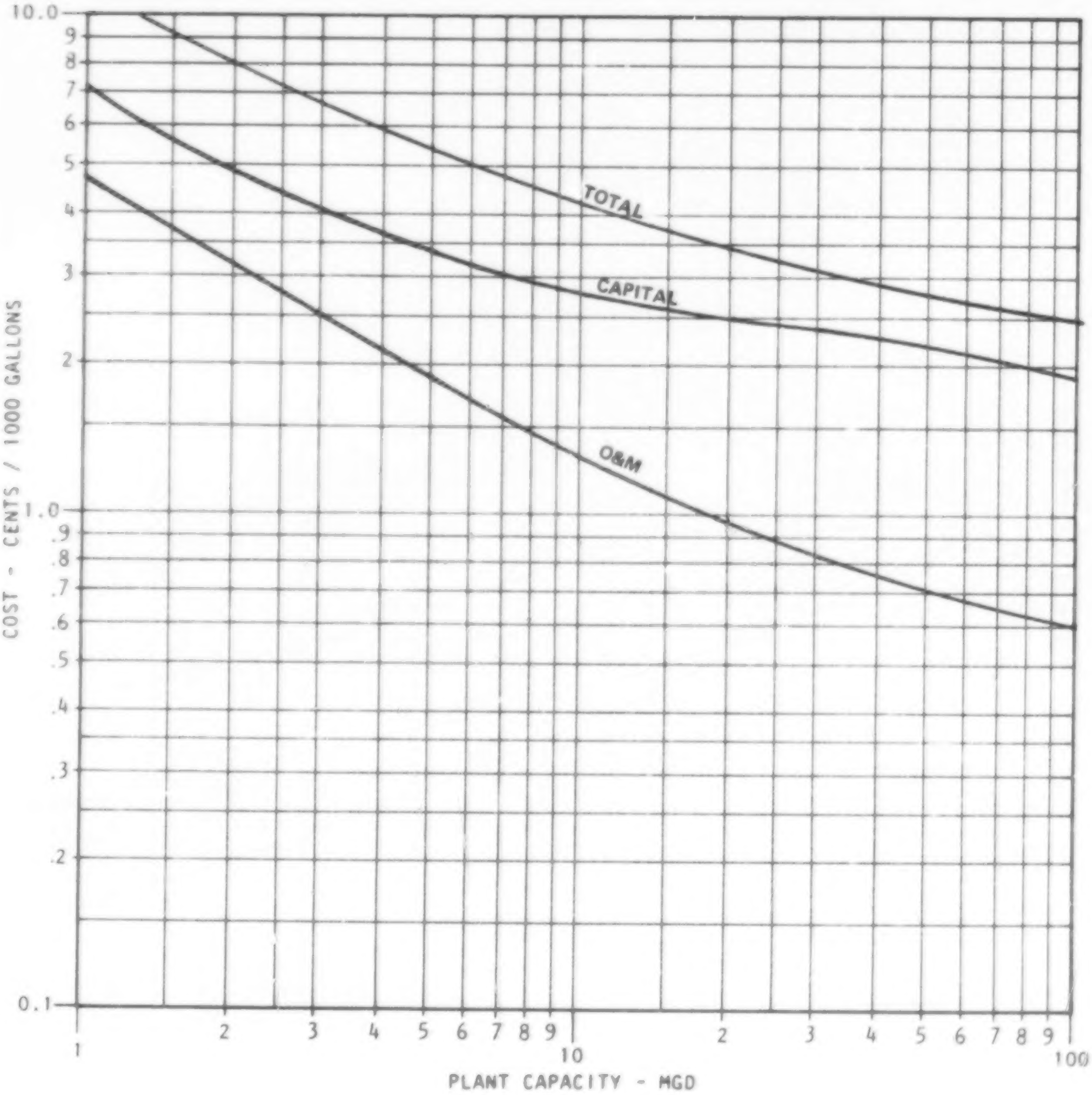


B-2. TRICKLING FILTER

Influent: Effluent From Primary Sedimentation – Single-Stage Lime Addition A-3

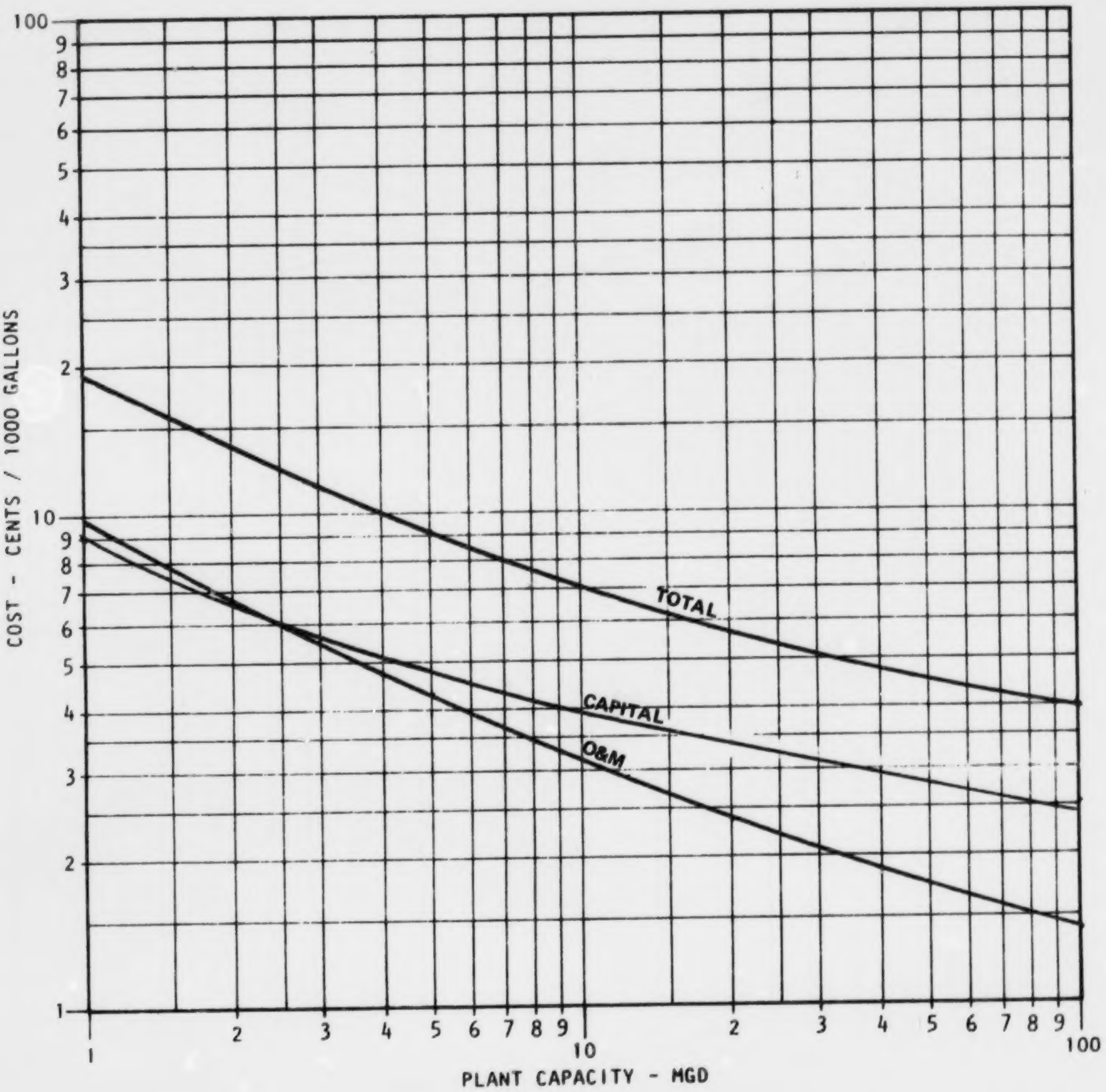


B-3. TRICKLING FILTER
Influent: Effluent From Primary Sedimentation – Alum or $FeCl_3$ Addition A-4 or A-5



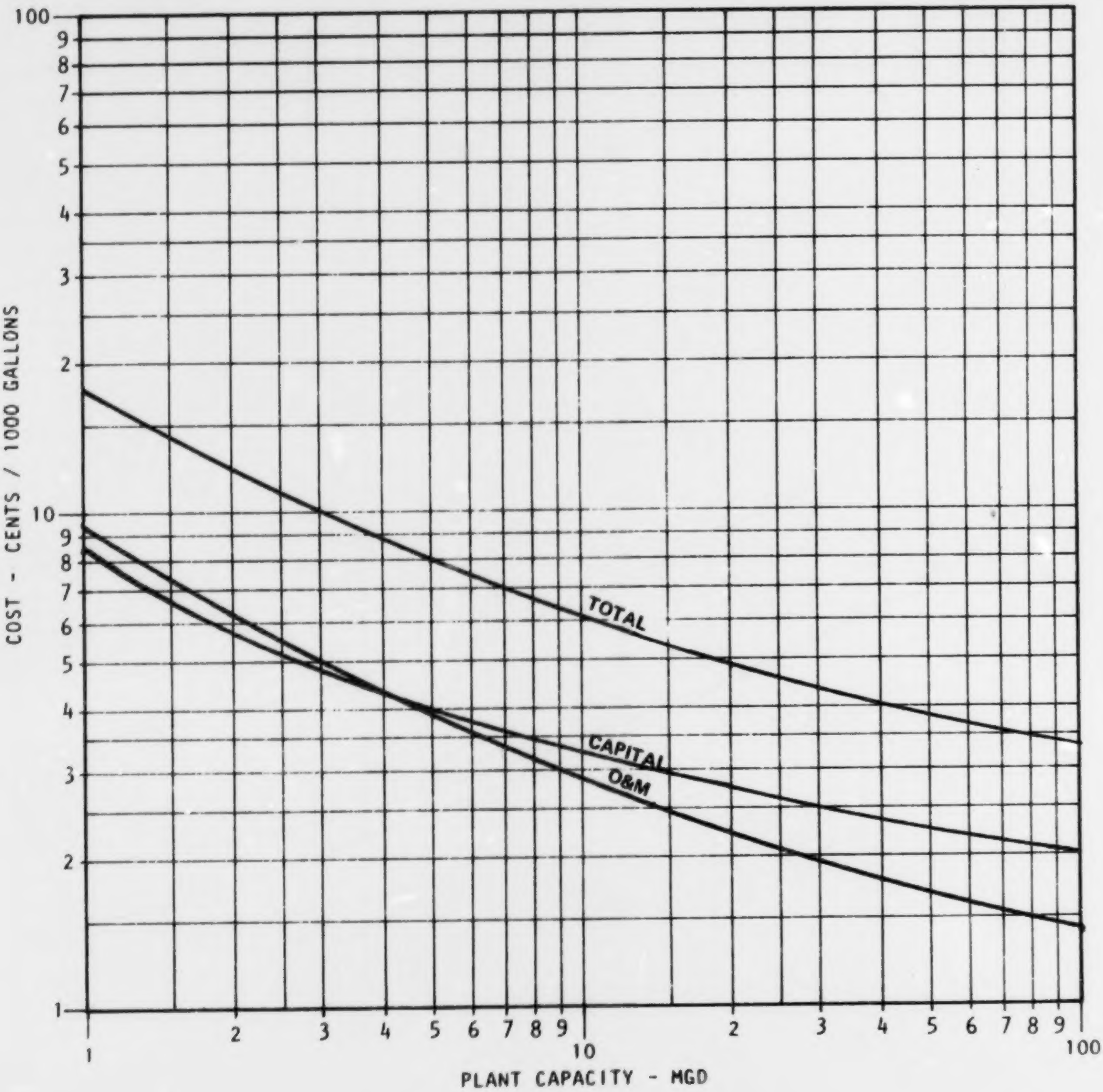
C-1. ACTIVATED SLUDGE – CONVENTIONAL

Influent: Effluent from Primary Sedimentation – Conventional A-1



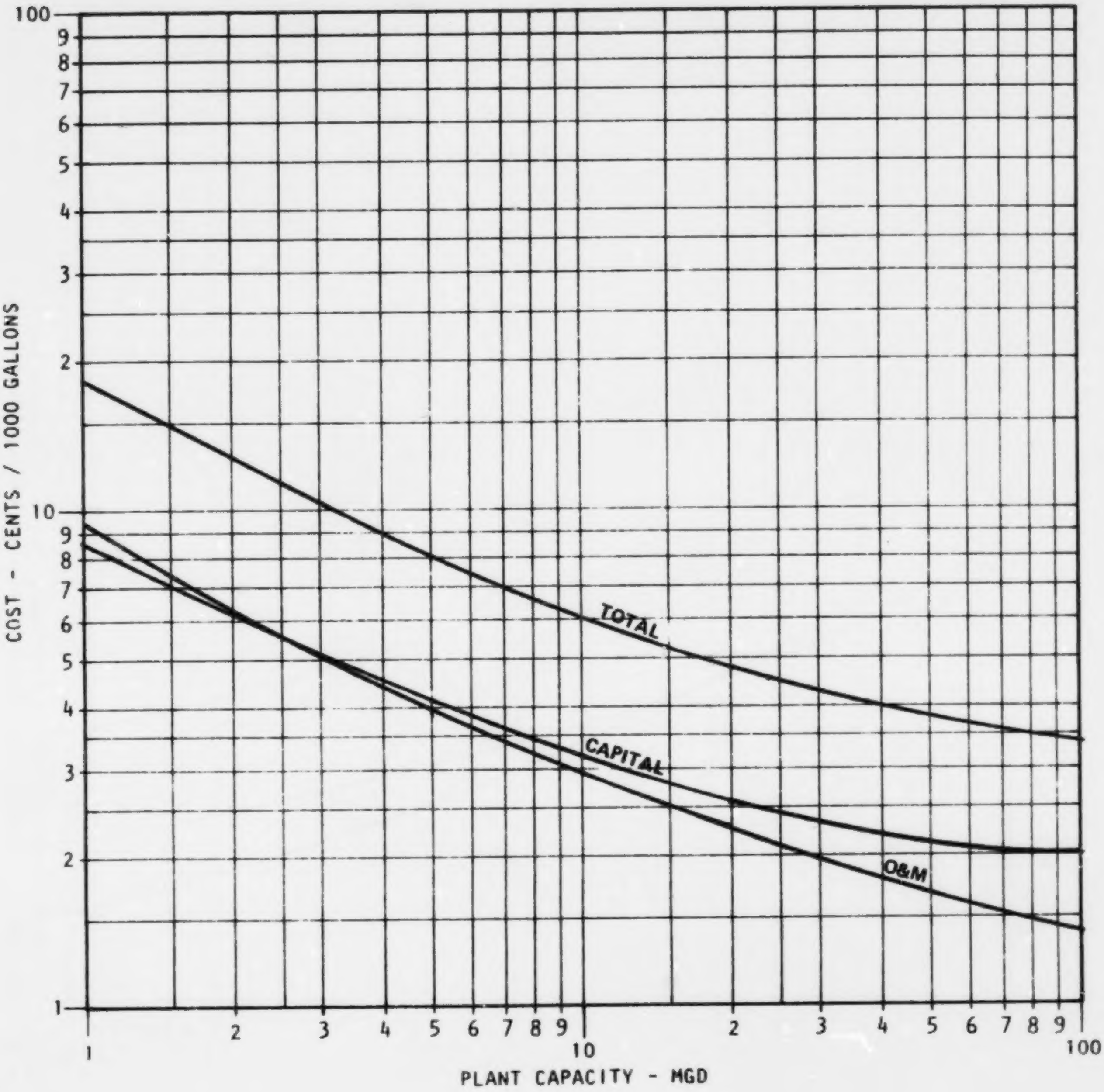
C-2. ACTIVATED SLUDGE

Influent: Effluent from Primary Sedimentation — Single-Stage Lime Addition A-3



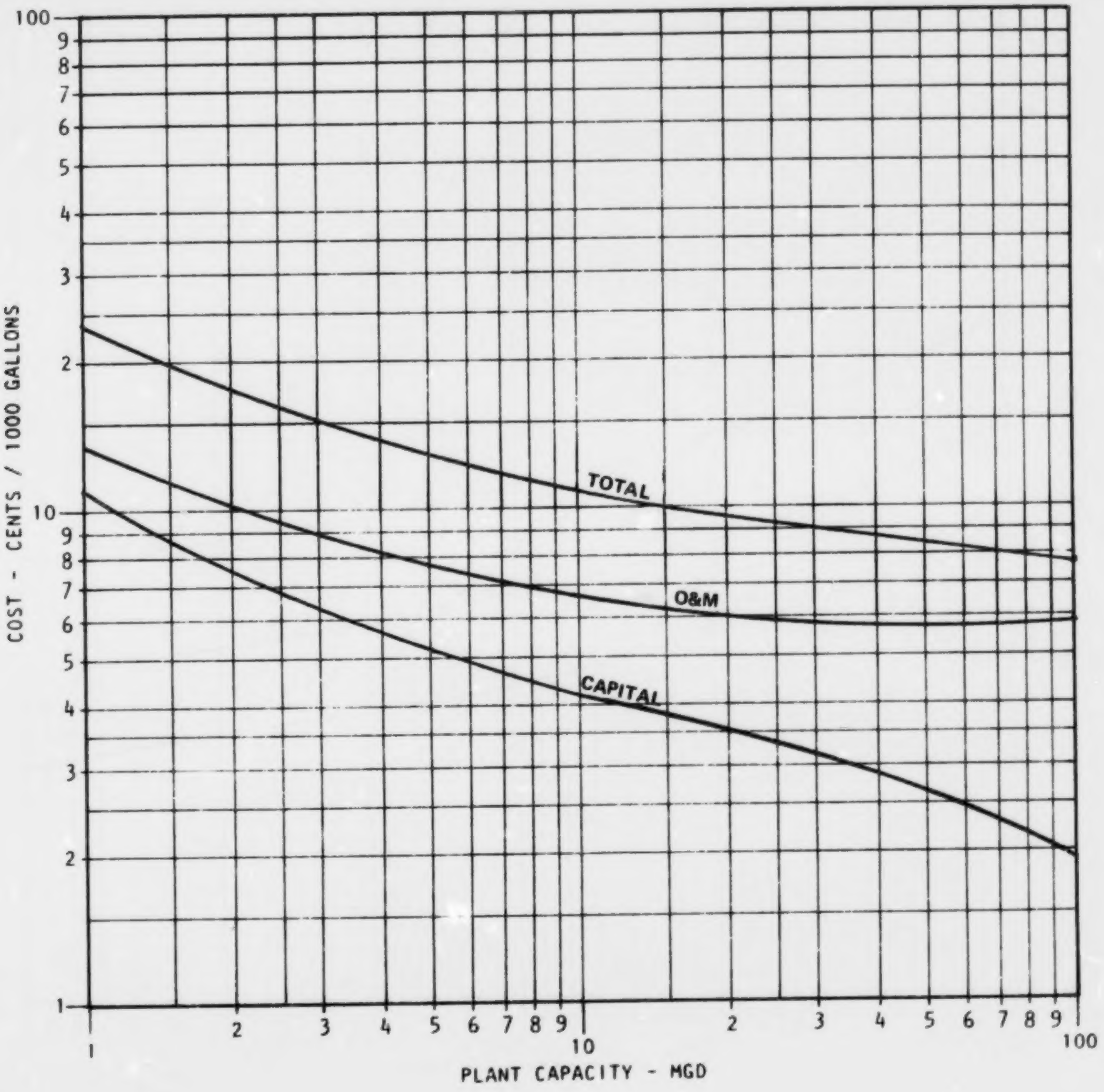
C-3. ACTIVATED SLUDGE

Influent: Effluent from Primary Sedimentation – Alum or $FeCl_3$ Addition A-4 or A-5



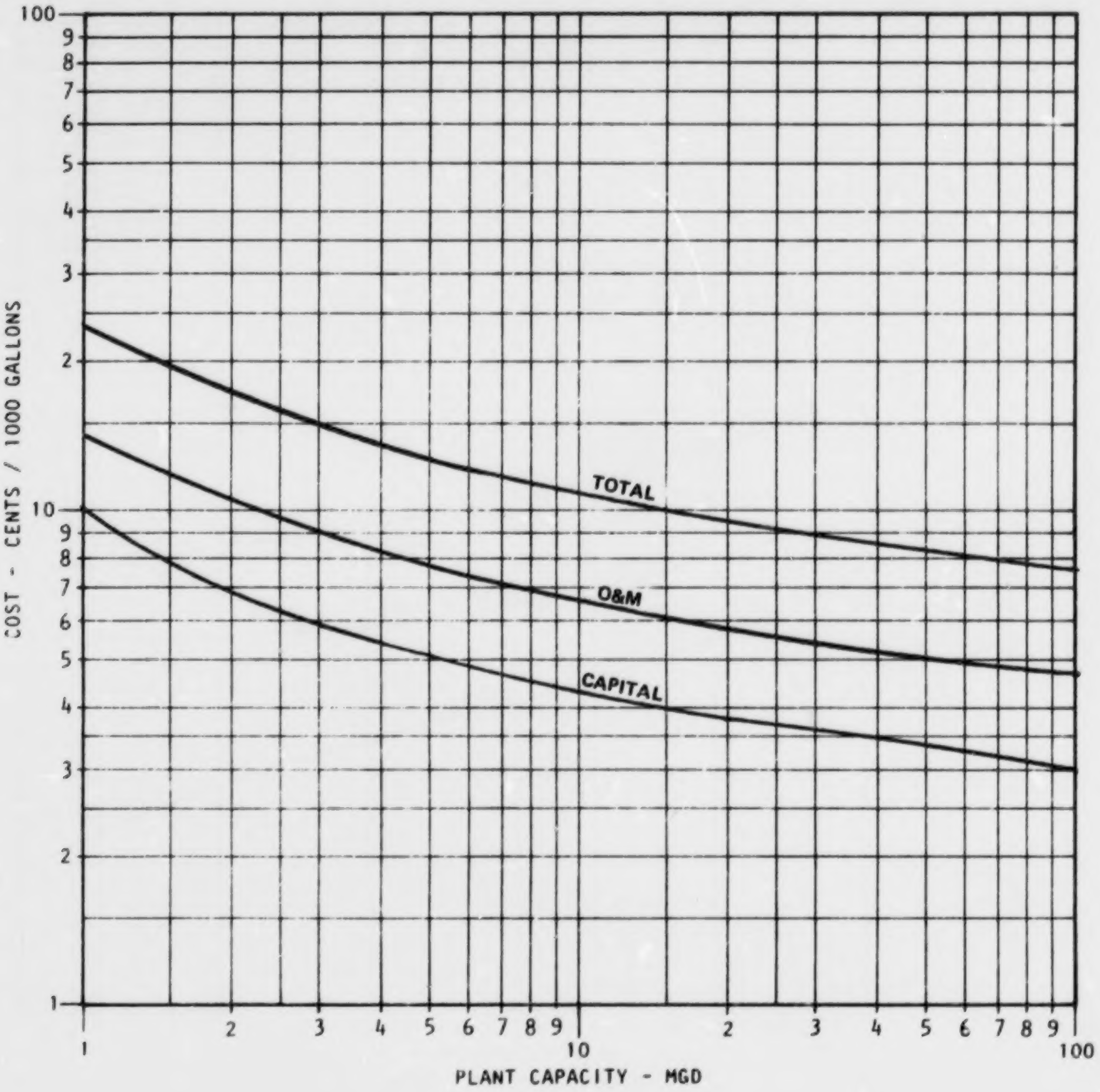
C-4. ACTIVATED SLUDGE + ALUM ADDITION

Influent: Effluent from Primary Sedimentation – Conventional A-1



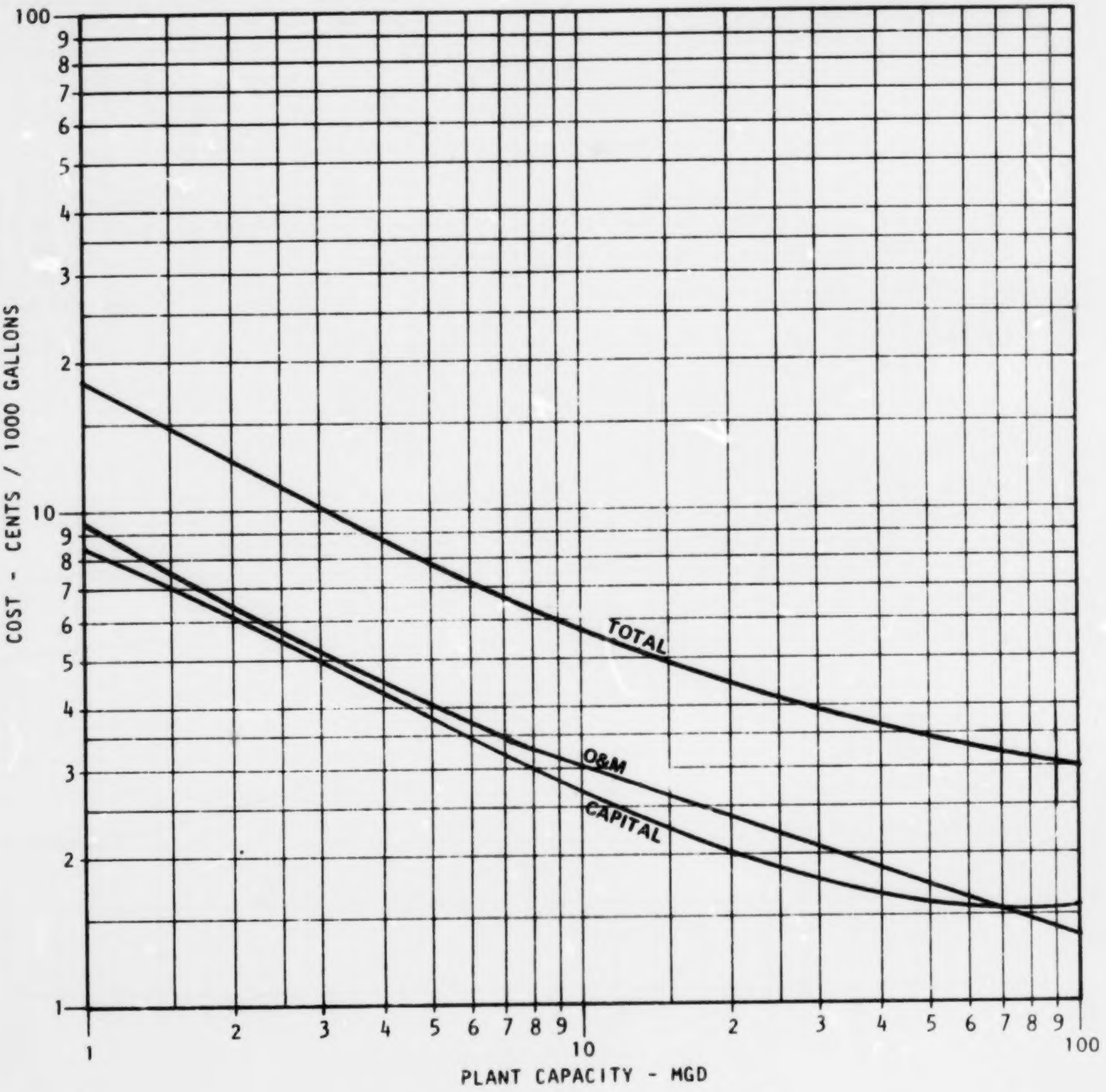
C-5. ACTIVATED SLUDGE – $FeCl_3$ ADDITION

Influent: Effluent from Primary Sedimentation – Conventional A-1

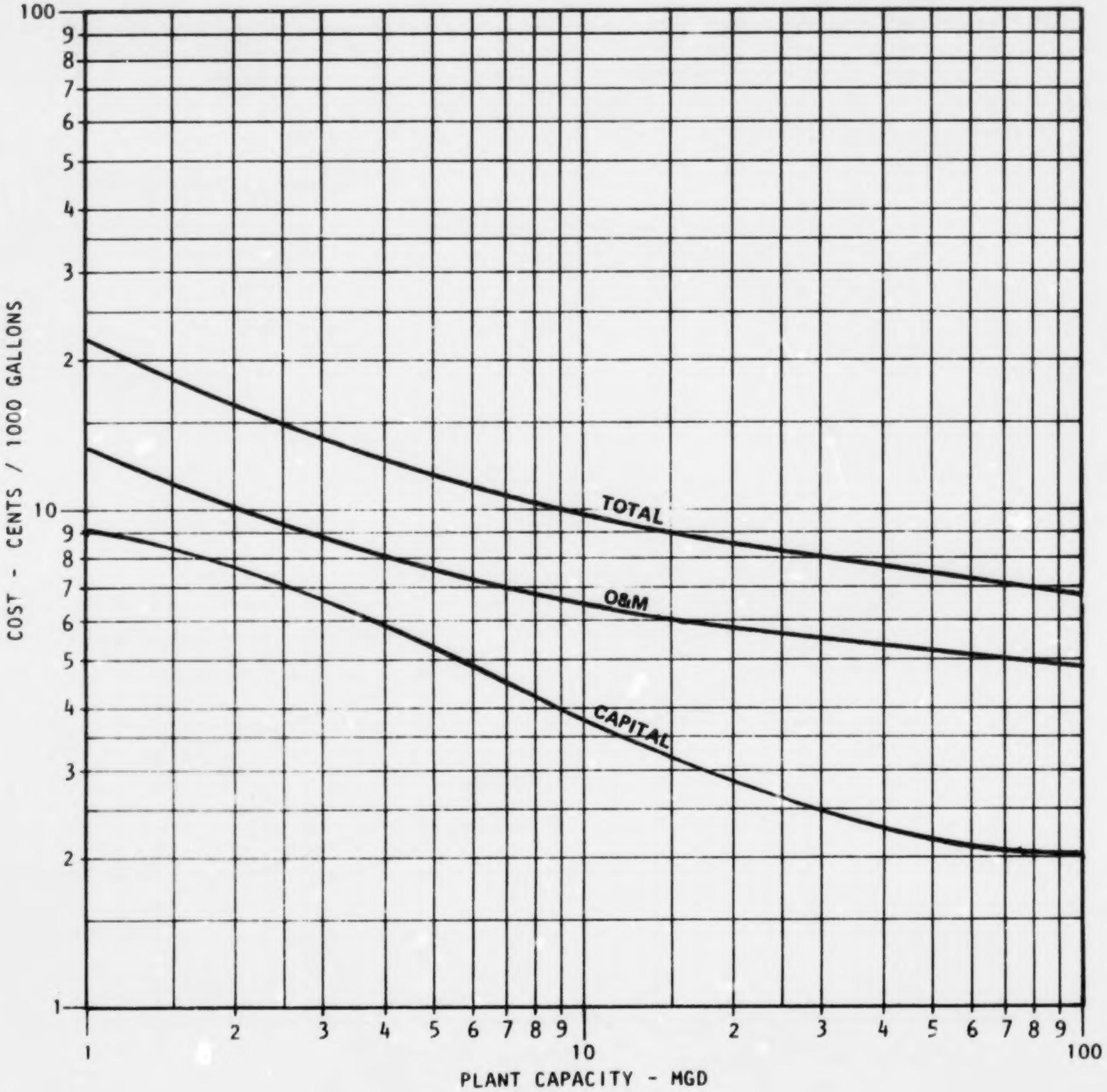


C-6. ACTIVATED SLUDGE – HIGH RATE

Influent: Effluent from Primary Sedimentation – Conventional A-1

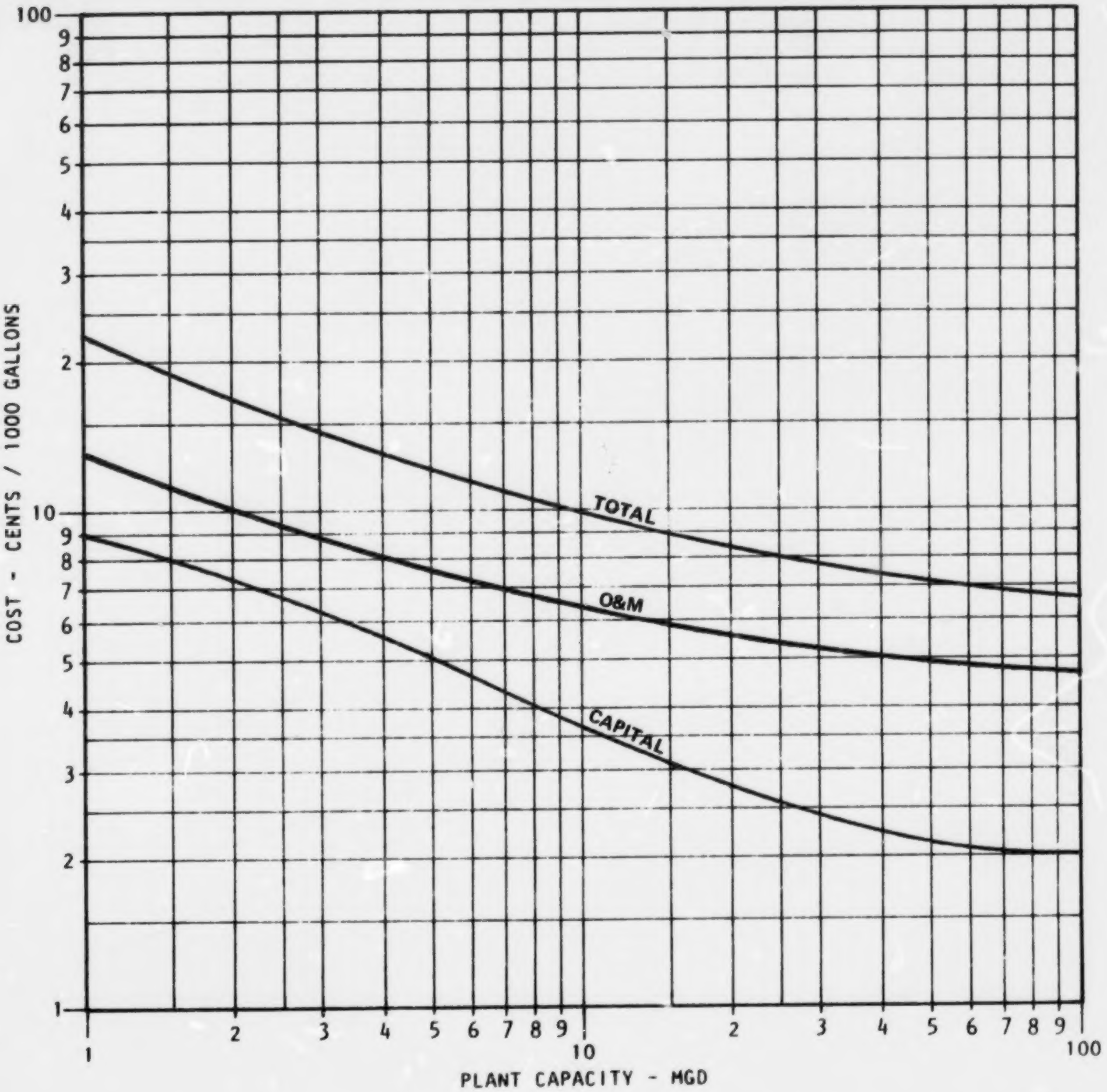


C-7. ACTIVATED SLUDGE – HIGH RATE + ALUM ADDITION
Influent: Effluent from Primary Sedimentation – Conventional A-1



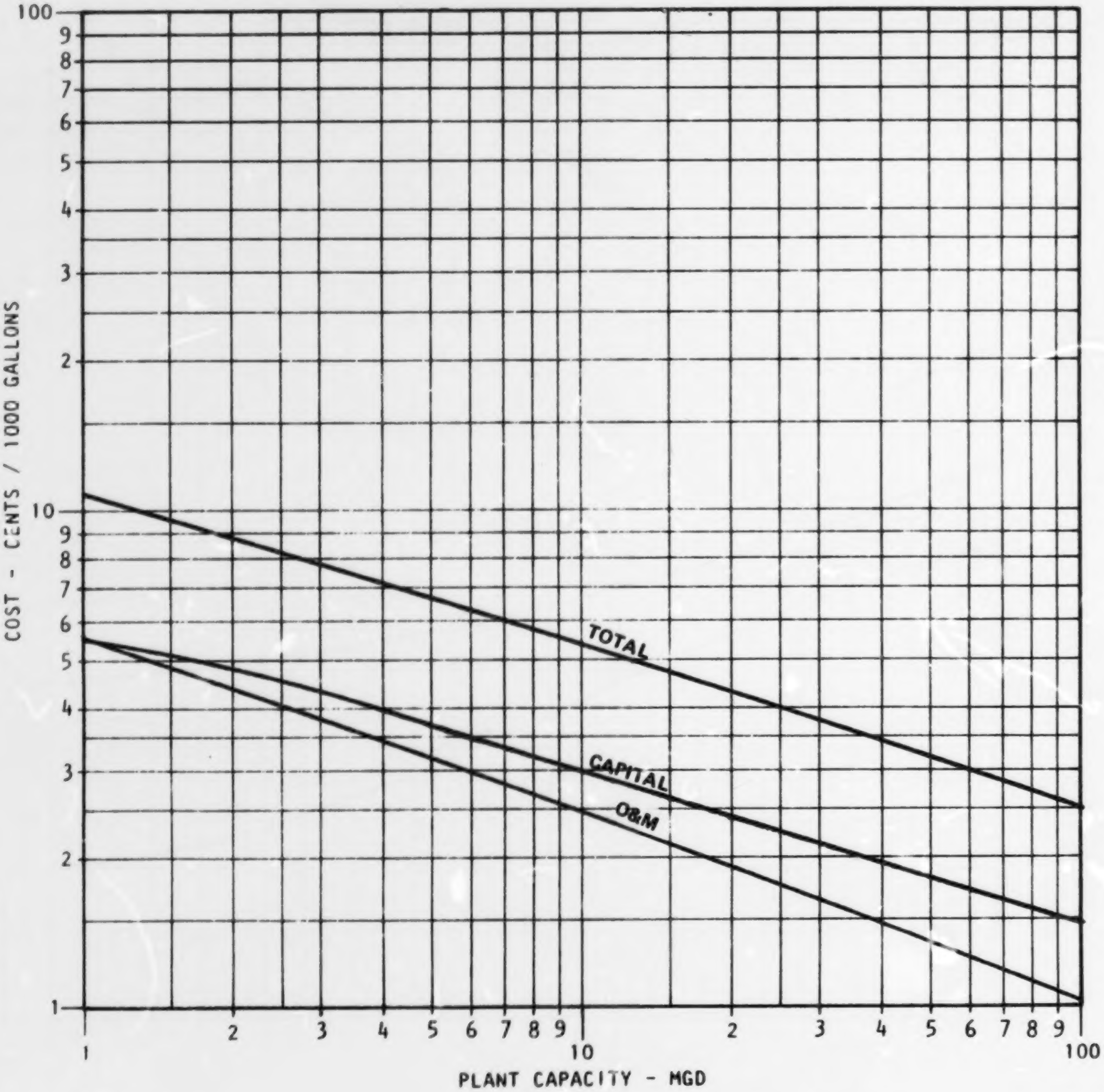
C-8. ACTIVATED SLUDGE – HIGH RATE + $FeCl_3$ ADDITION

Influent: Effluent from Primary Sedimentation – Conventional A-1



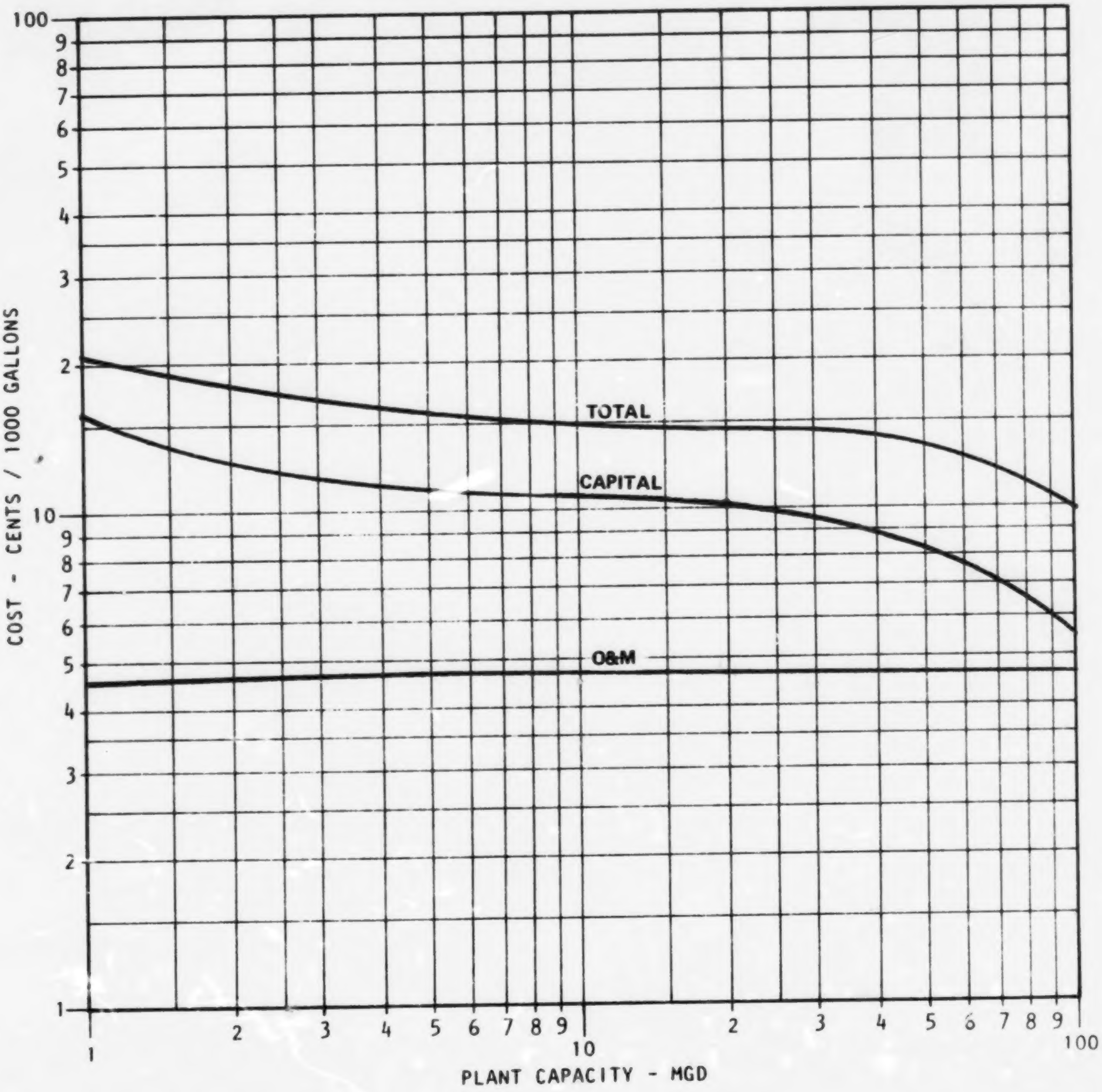
D. FILTRATION

Influent: Effluent from Primary Sedimentation — Two Stage Lime Addition
A-2
Activated Sludge — Alum or $FeCl_3$ Addition
C-4 or C-5
Two Stage Tertiary Lime Treatment
F-1 or F-2
Trickling Filter B-2, B-3
Activated Sludge C-2, C-3
Biological Nitrification G-1, G-2, G-3, G-4
Biological Denitrification H
Breakpoint Chlorination J
Ammonia Stripping K

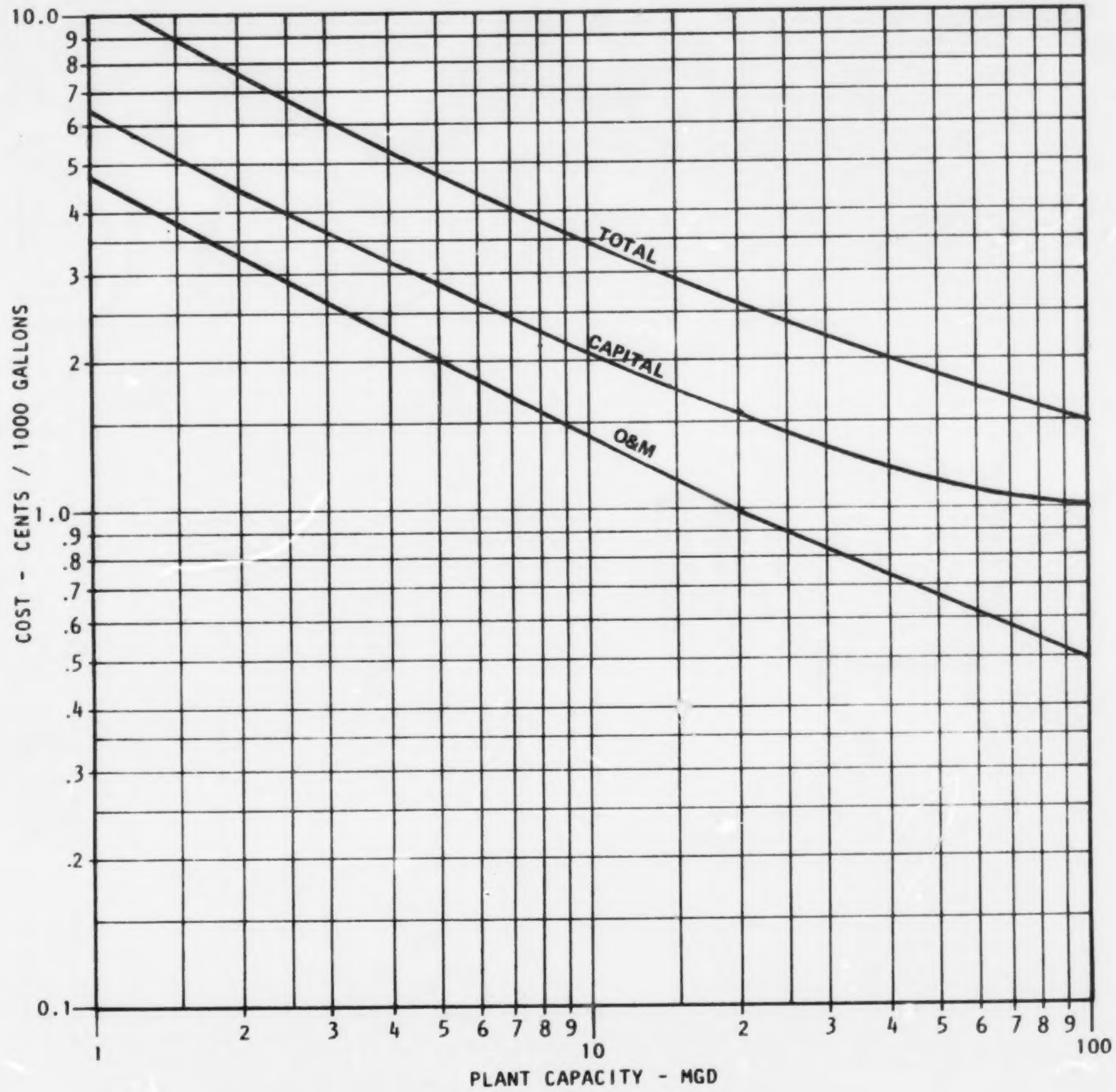


E. ACTIVATED CARBON

Influent: Effluent from Filtration D

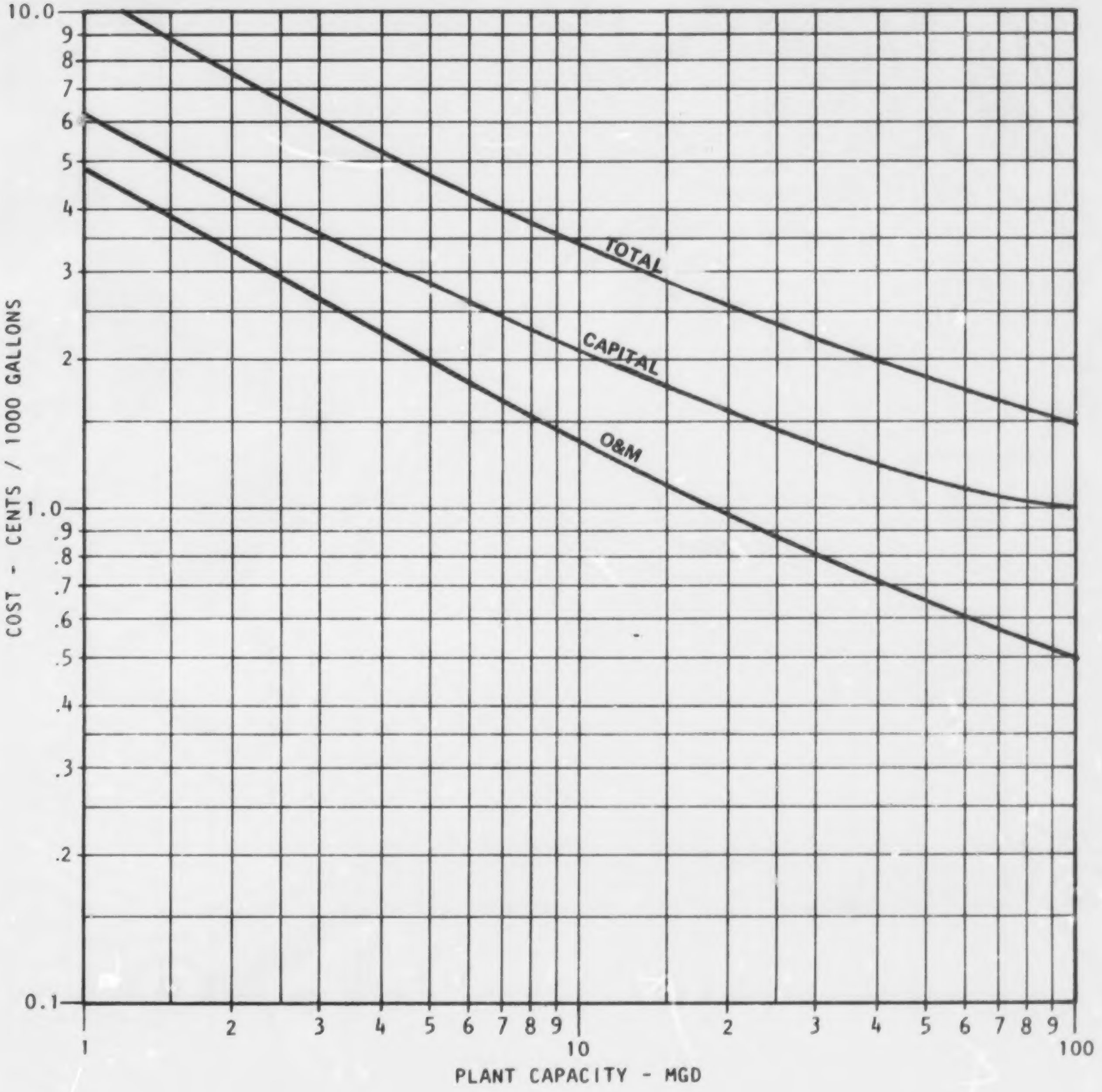


F-1. TWO-STAGE TERTIARY LIME TREATMENT
Influent: Effluent from Trickling Filter System B-1



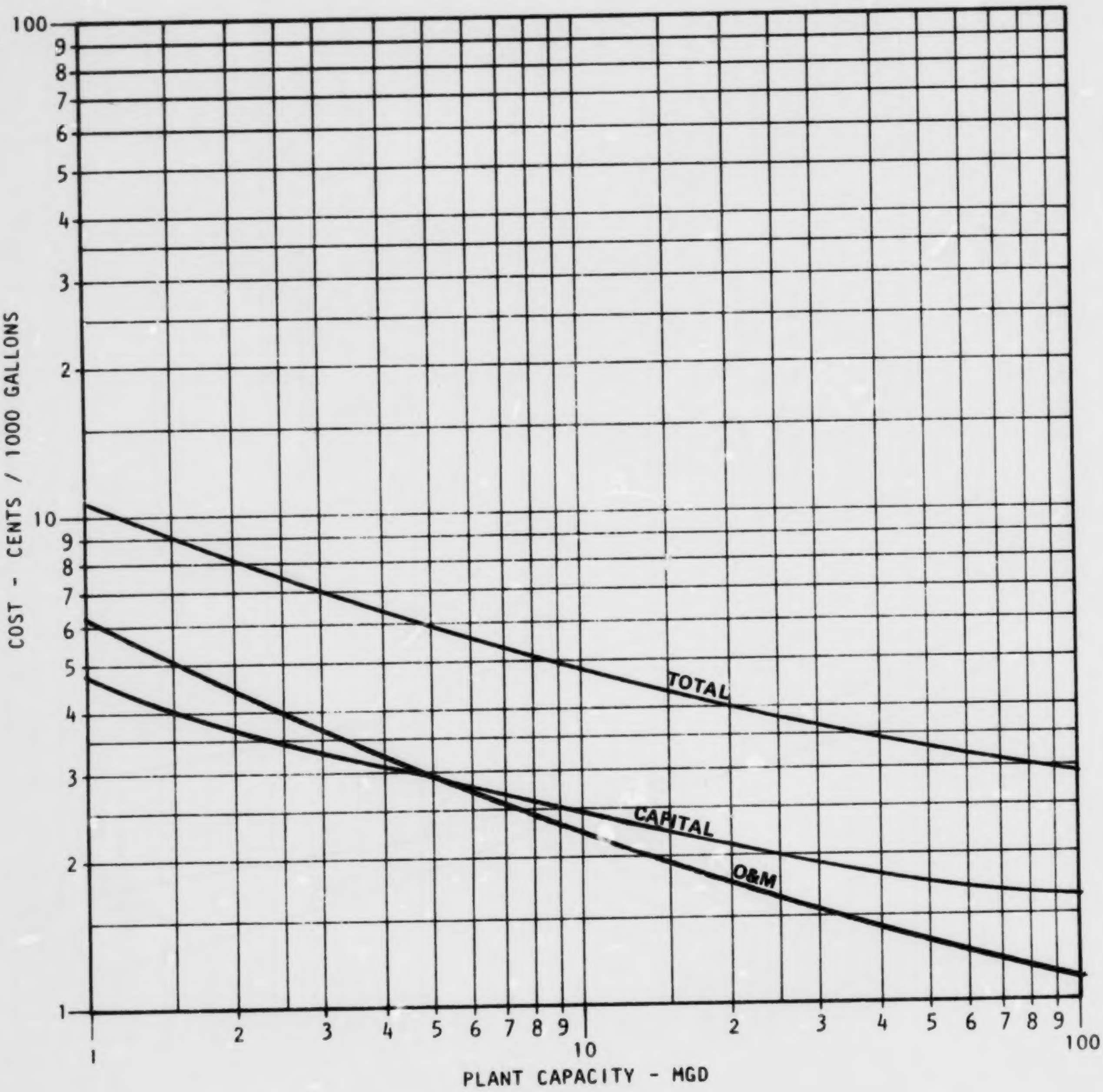
F-2. TWO-STAGE TERTIARY LIME TREATMENT

Influent: Effluent from Conventional Activated Sludge C-1

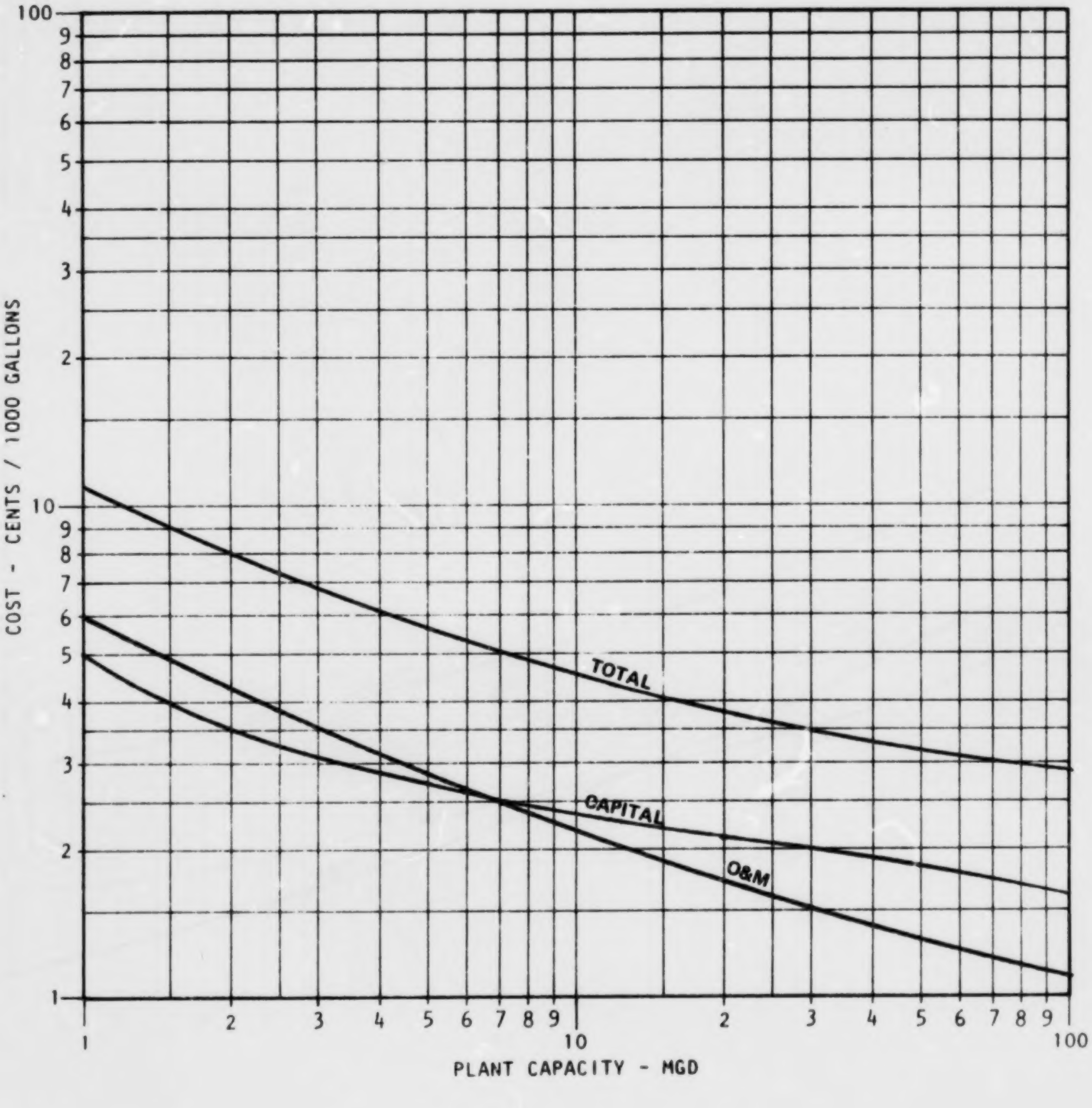


G-1. BIOLOGICAL NITRIFICATION

Influent: **Effluent from High Rate Activated Sludge C-6**

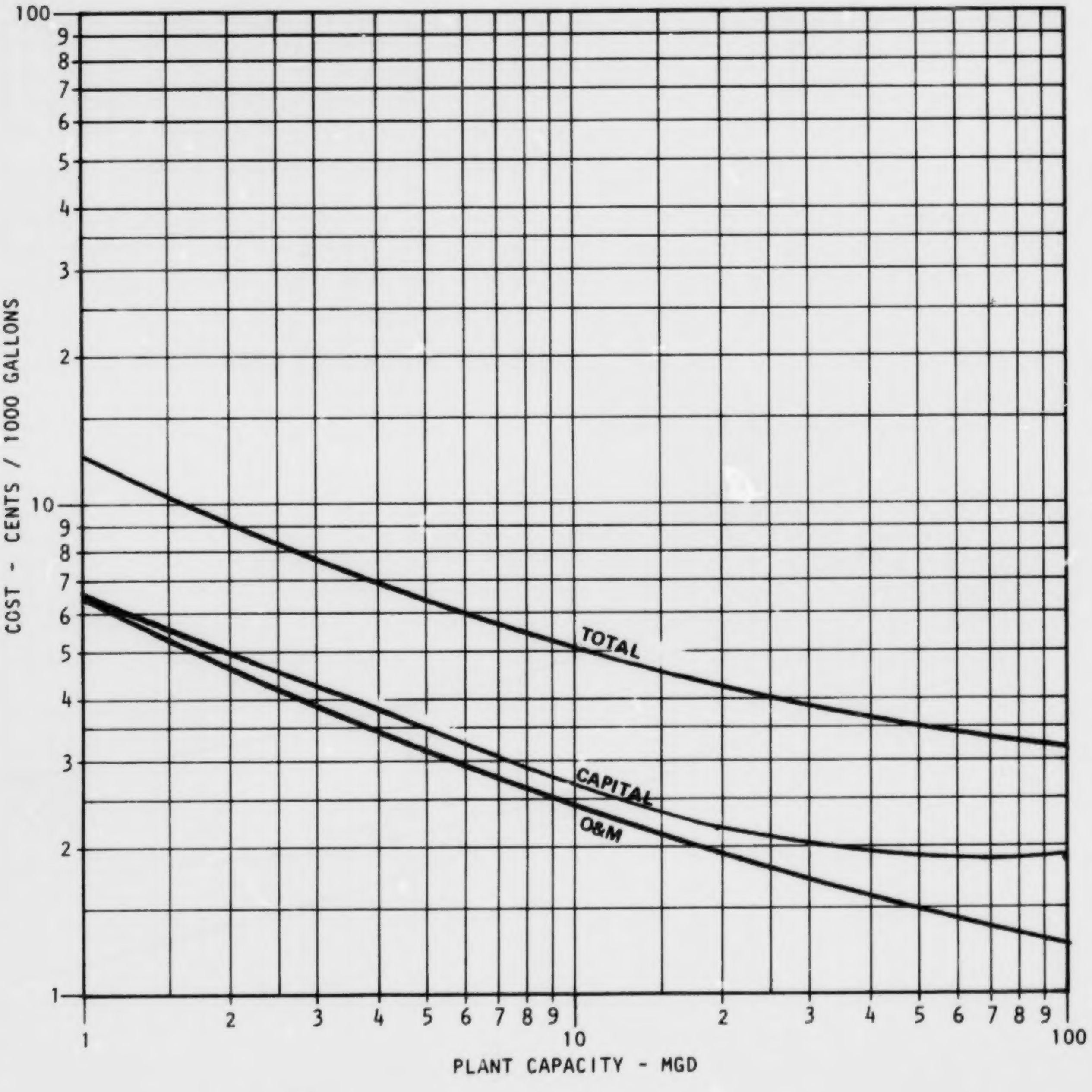


G-2. BIOLOGICAL NITRIFICATION
Influent: Effluent from Trickling Filter System B-1



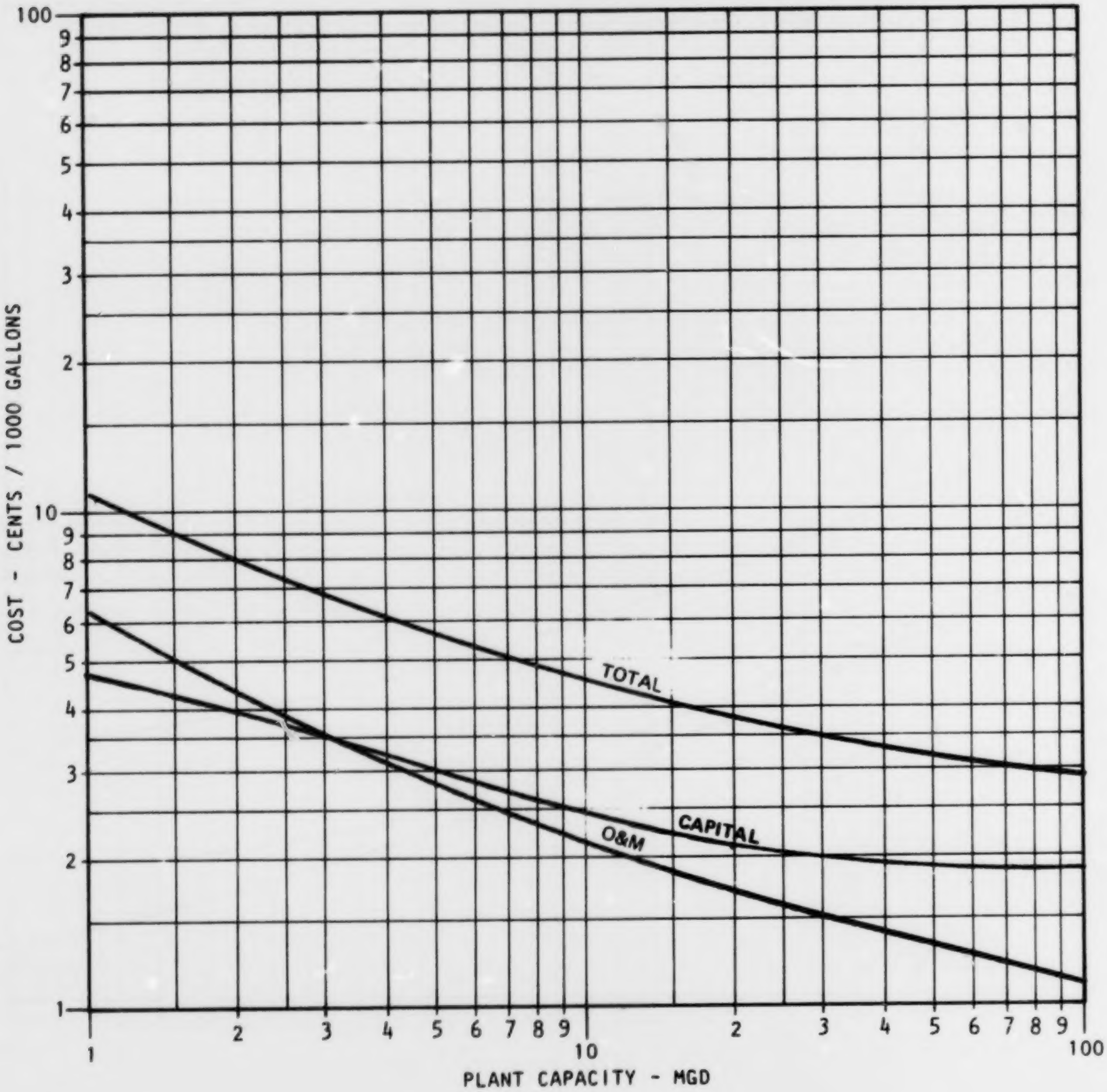
G-3. BIOLOGICAL NITRIFICATION

Influent: Effluent from Primary Sedimentation-Single Stage Lime Addition
A-3
Primary Sedimentation – Alum or $FeCl_3$ Addition
A-4 or A-5



G-4. BIOLOGICAL NITRIFICATION

Influent: Effluent from Primary Sedimentation – 2 Stage Lime Addition A-2
or High Rate Activated Sludge + Alum or $FeCl_3$ Addition C-7 or C-8



H. BIOLOGICAL DENITRIFICATION

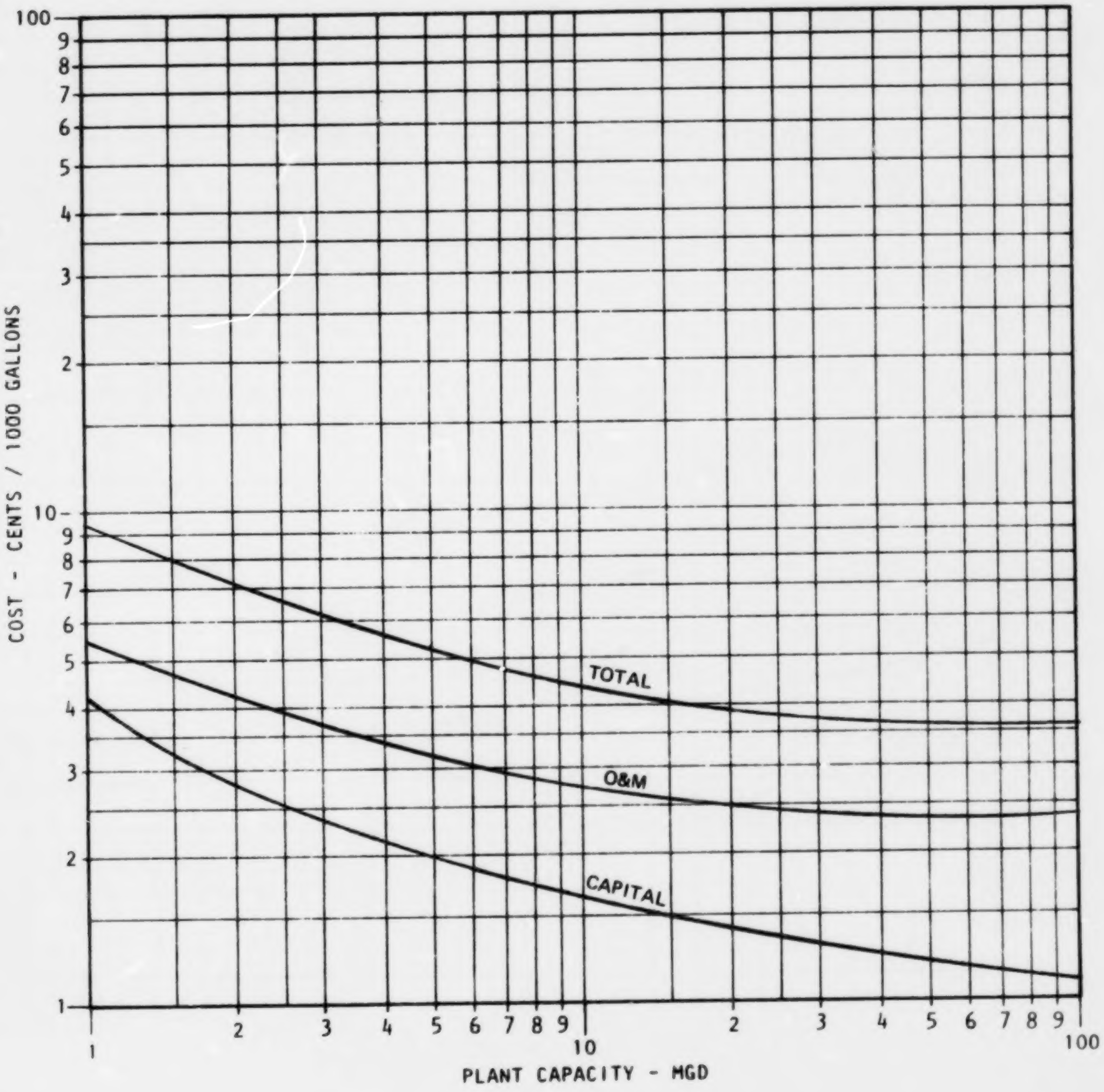
Influent: Nitrification Process Effluent

G-1

G-2

G-3

G-4



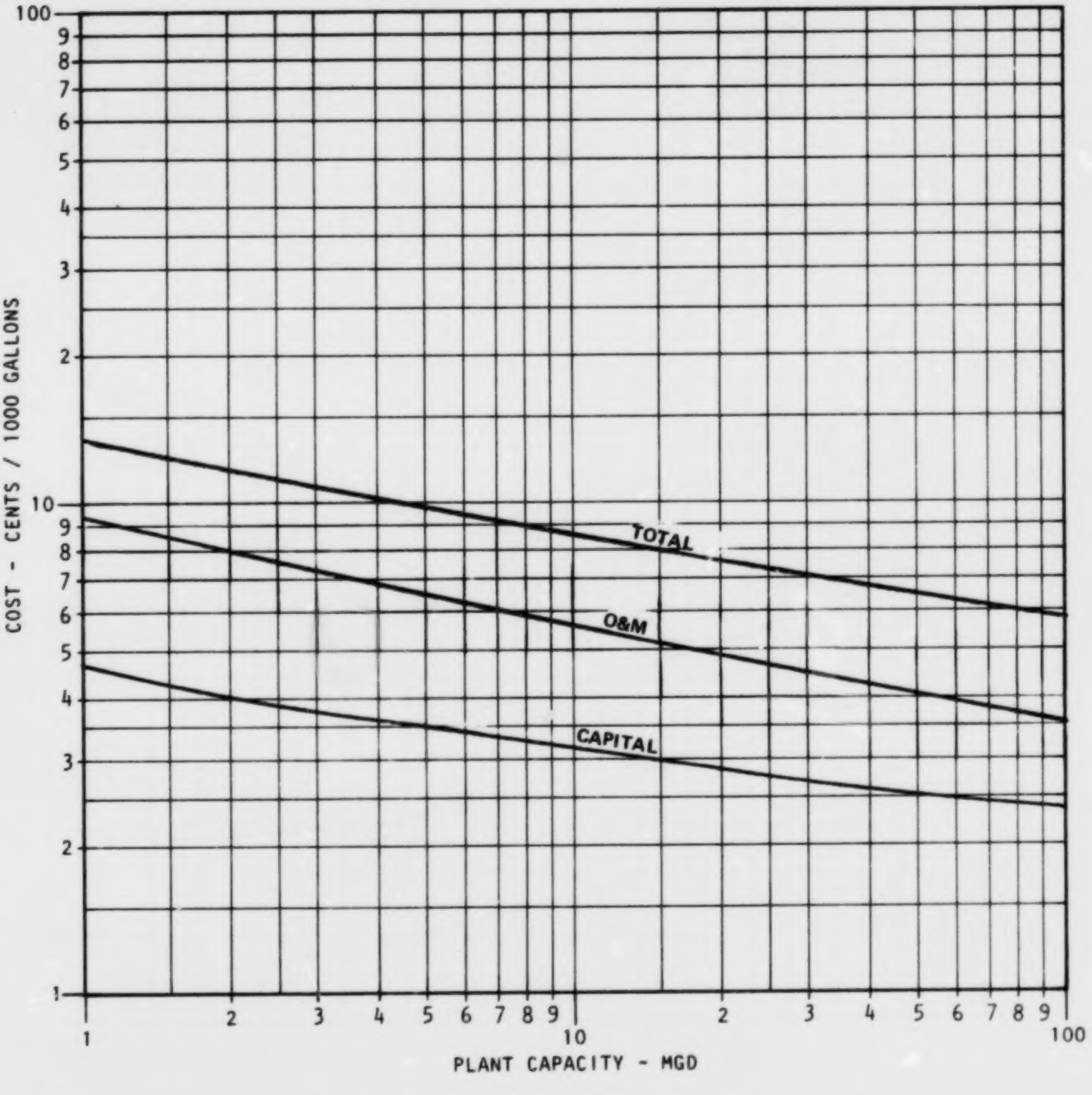
I. ION-EXCHANGE

Influent: Filtration - Effluent

D

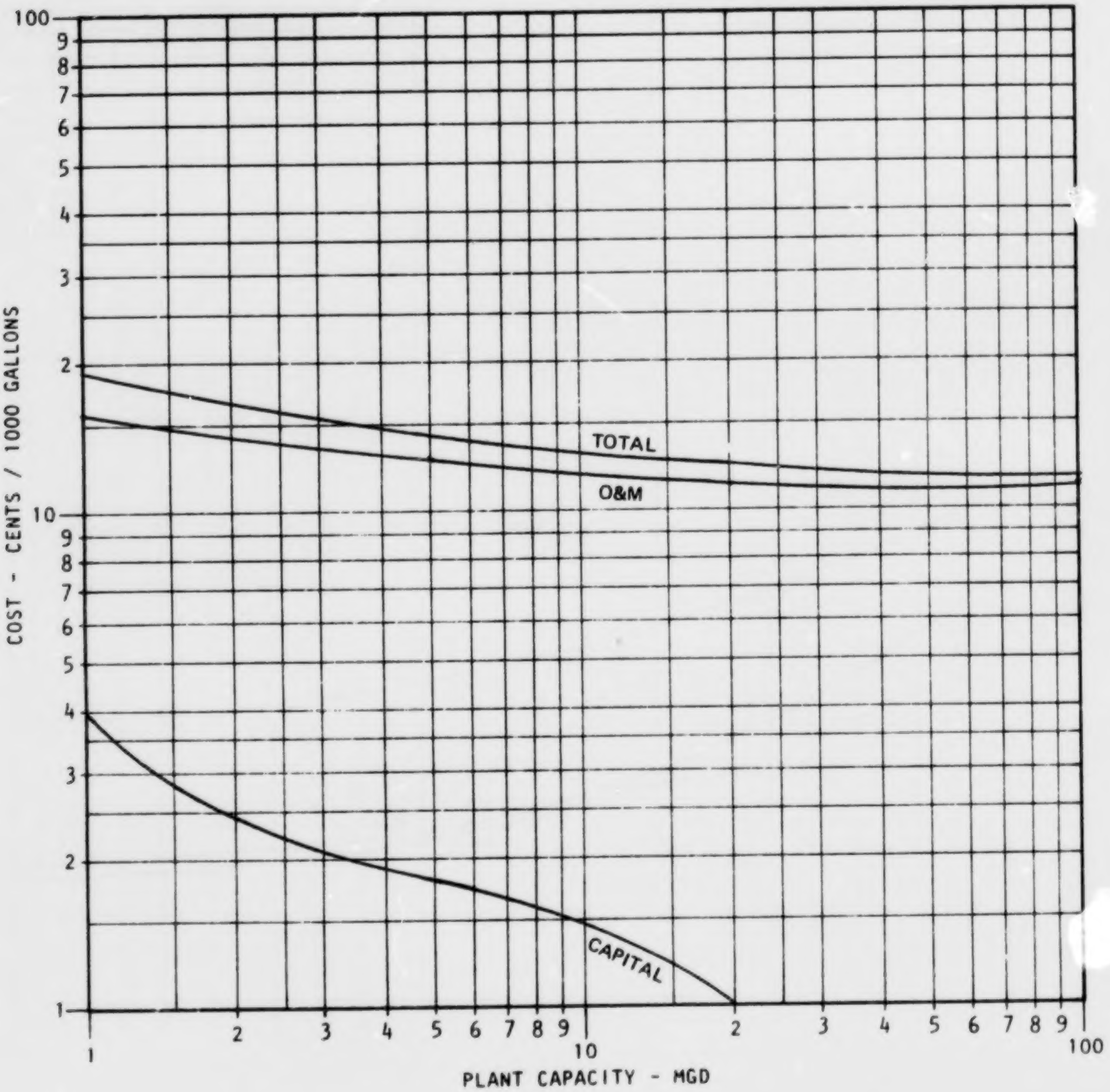
Activated Carbon Treatment Effluent

E



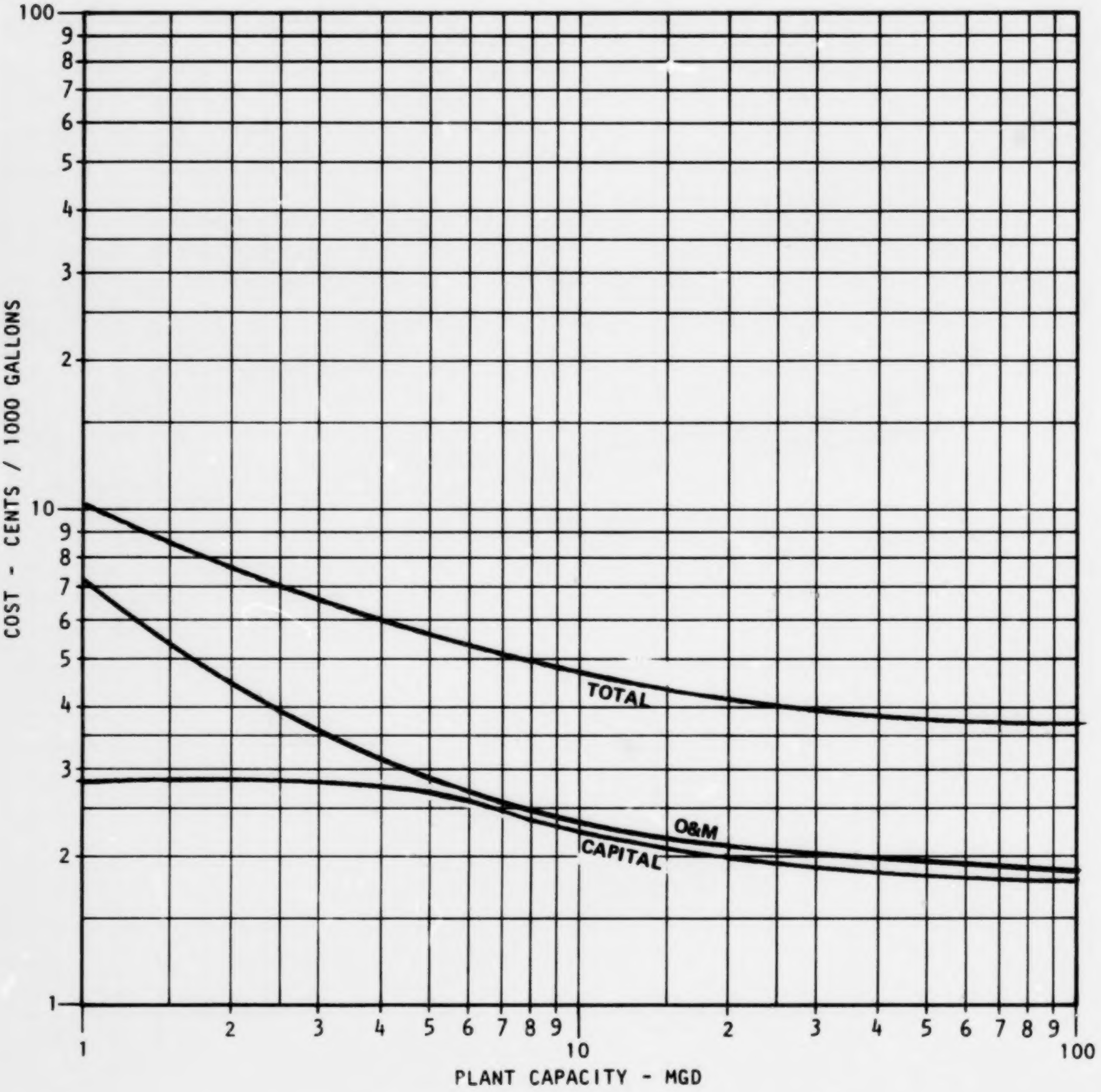
J. BREAK POINT CHLORINATION

Influent: Effluent from A-2, B-1, B-2, B-3, C-1, C-2, C-3, C-4, C-5, F-1, F-2

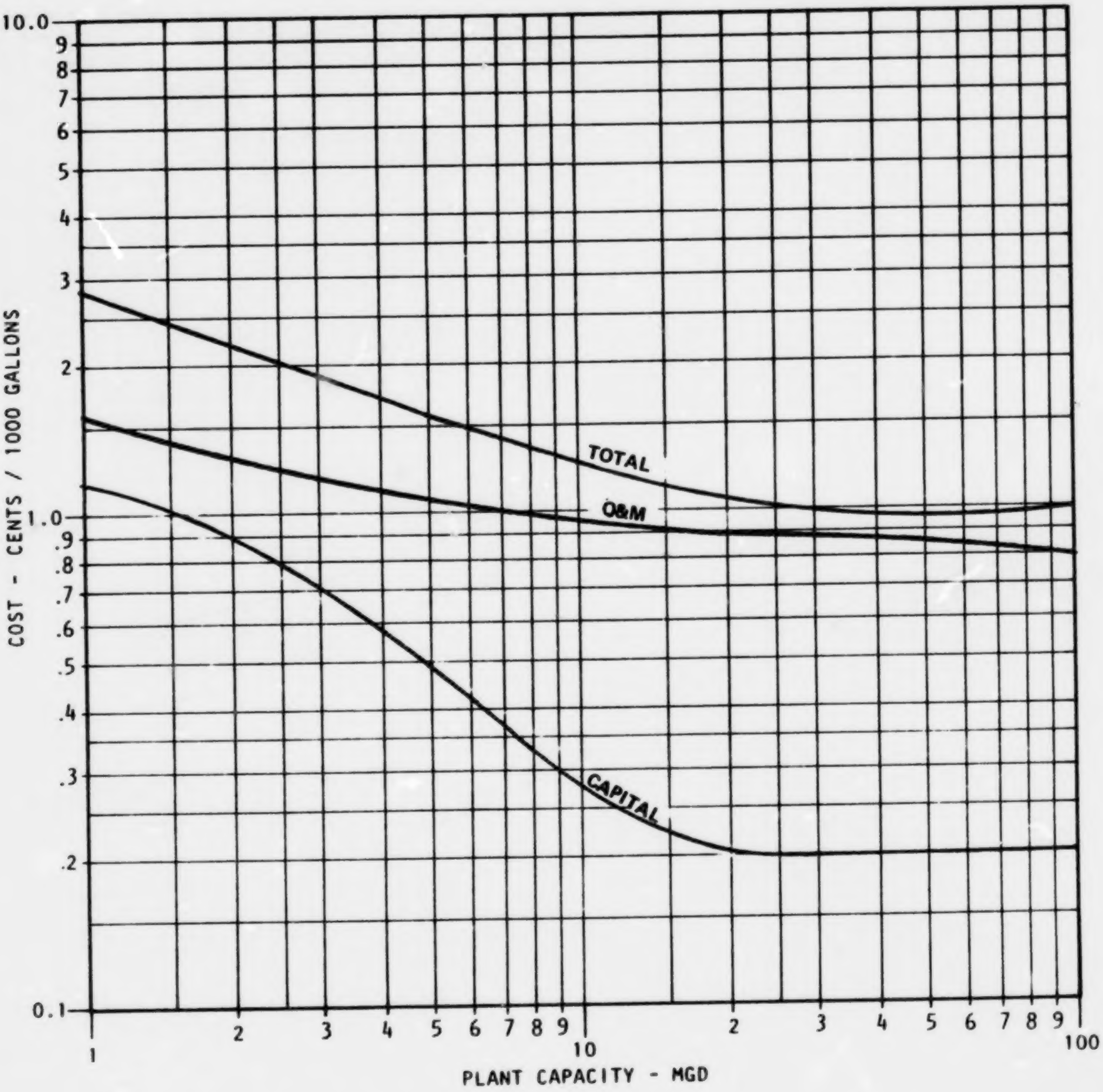


K. AMMONIA STRIPPING

Influent: Effluent from First Stage of Two Stage Tertiary Lime Treatment F-1 or F-2

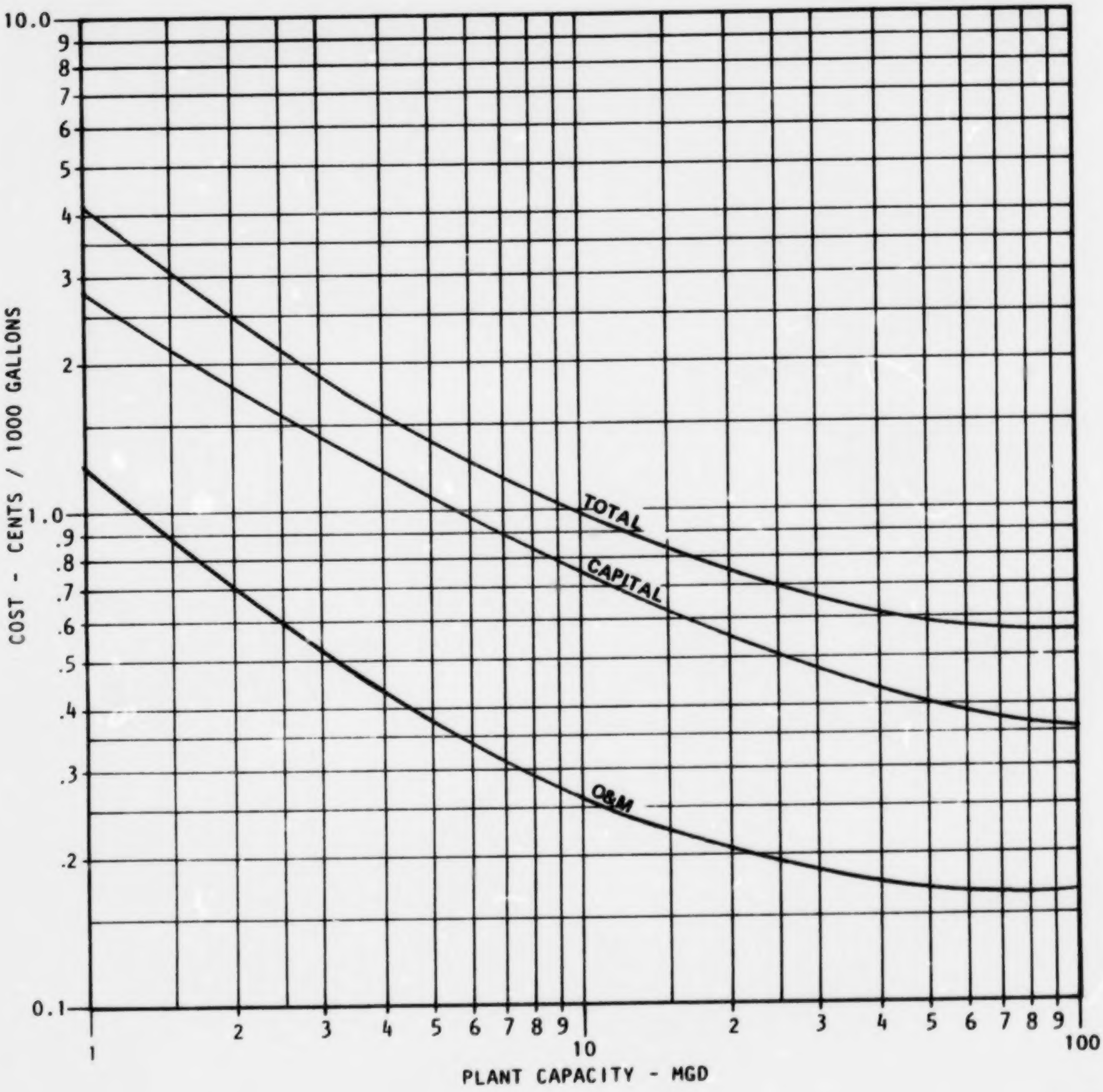


R. DISINFECTION
Influent: Any Process Effluent



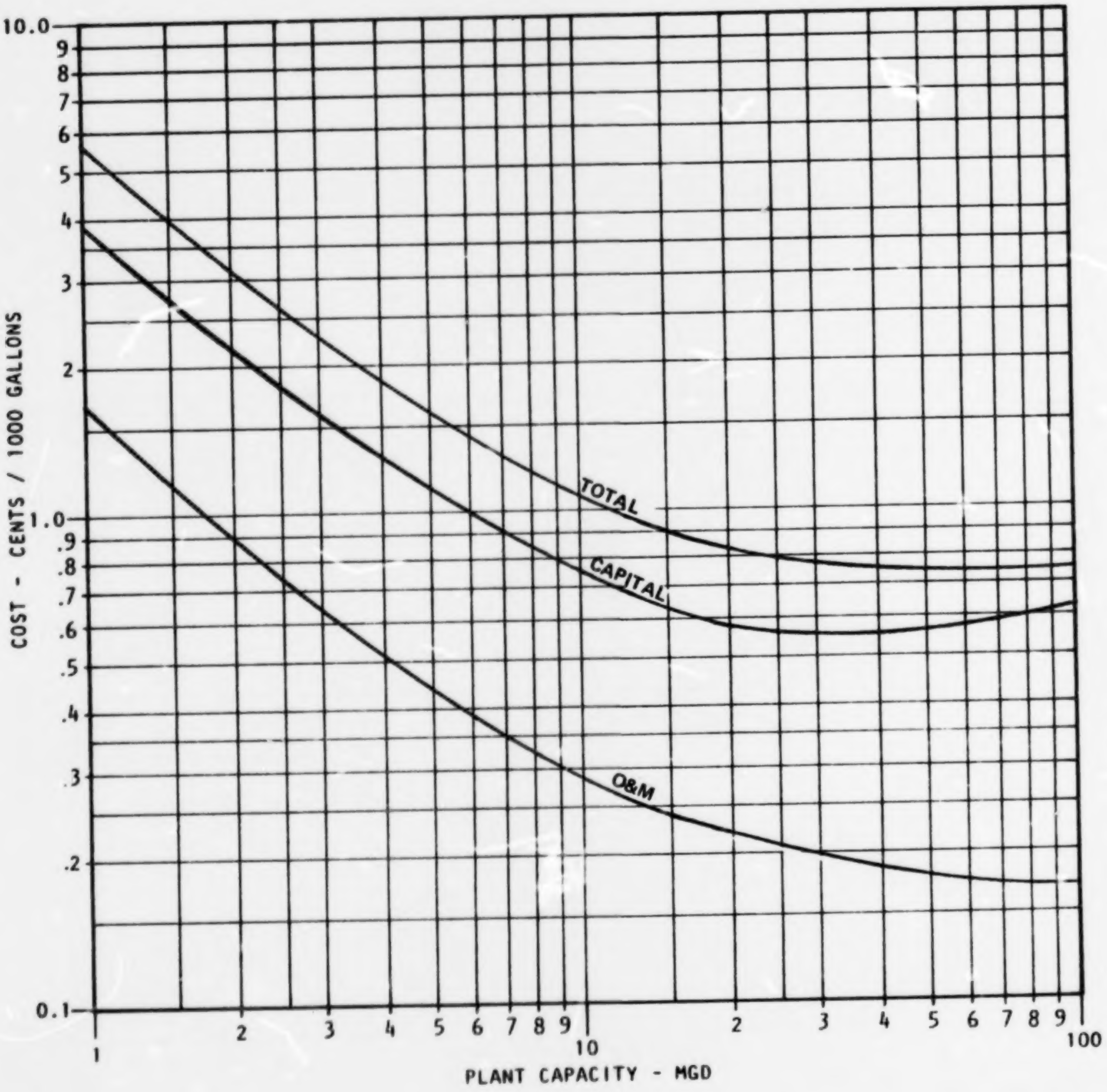
L-1. ANAEROBIC DIGESTION

Sludge Influent: Primary Sedimentation – Conventional plus Trickling Filter
A-1 + B-1
Primary Sedimentation – Conventional plus Activated Sludge – Conventional
A-1 + C-1
Primary Sedimentation – Conventional plus Activated Sludge – High rate
A-1 + C-6



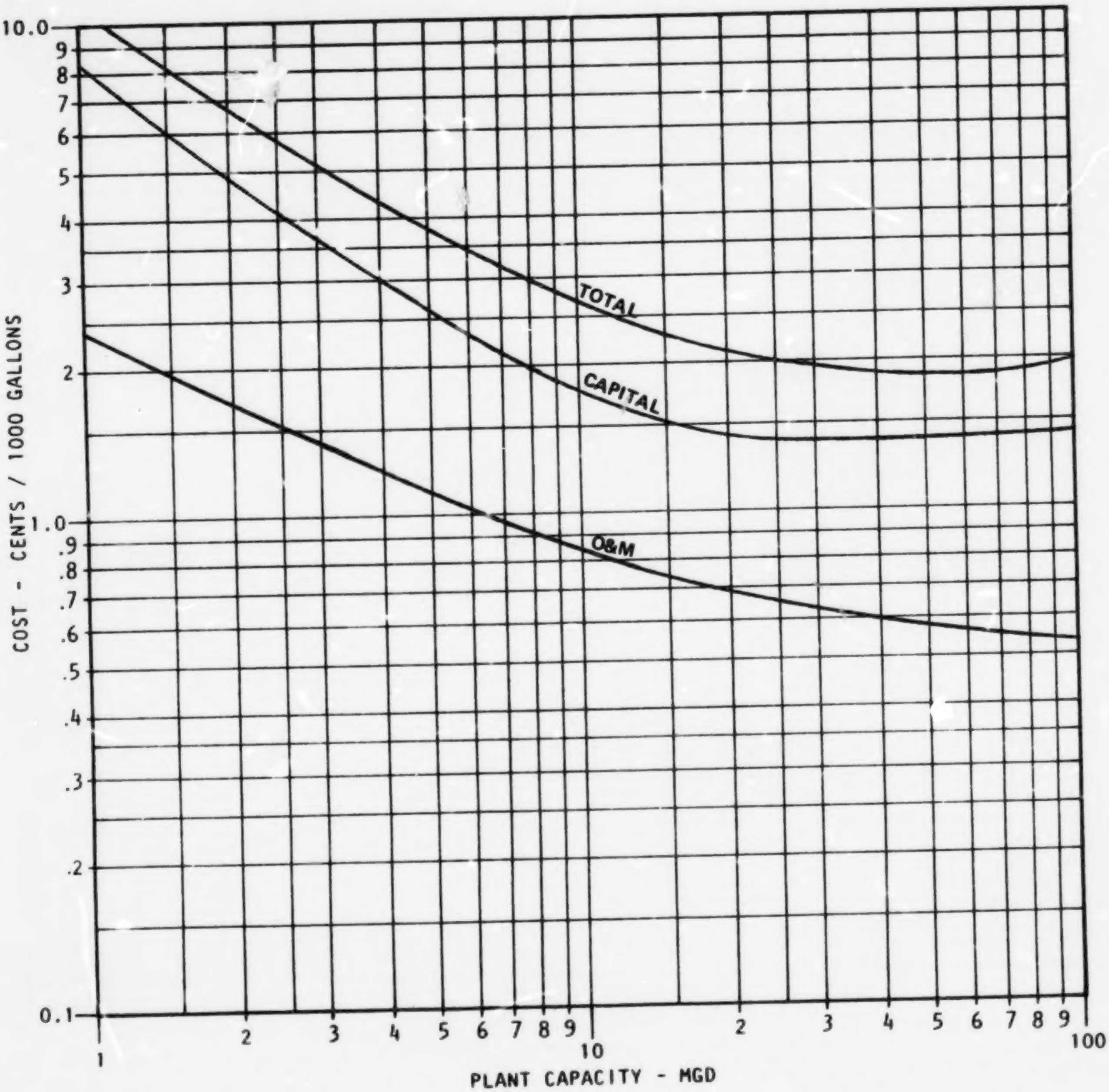
L-2. ANAEROBIC DIGESTION

Sludge Influent: Primary Sedimentation – Conventional and Activated Sludge
or High Rate Activated Sludge – Alum or $FeCl_3$ Addition
A-1 + C-4 or C-5
A-1 + C-7 or C-8
Primary Sedimentation – Alum or $FeCl_3$ Addition + Activated
Sludge or Trickling Filter
A-4 + B-3 or C-3
A-5 + B-3 or C-3



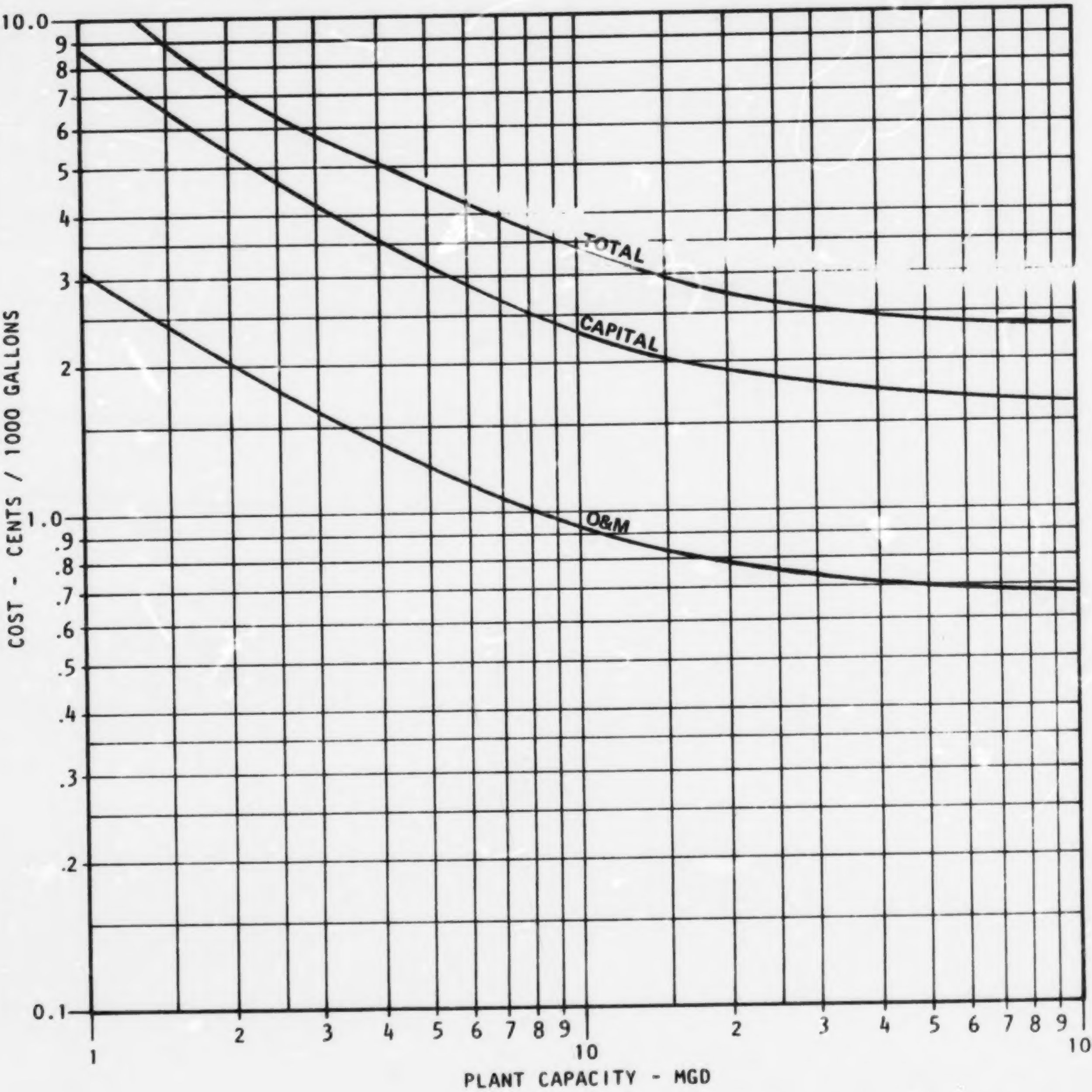
M-1. HEAT TREATMENT

Sludge Influent: **Biological Primary + Secondary — Conventional or High rate**
A-1 + B-1
A-1 + C-1
A-1 + C-6



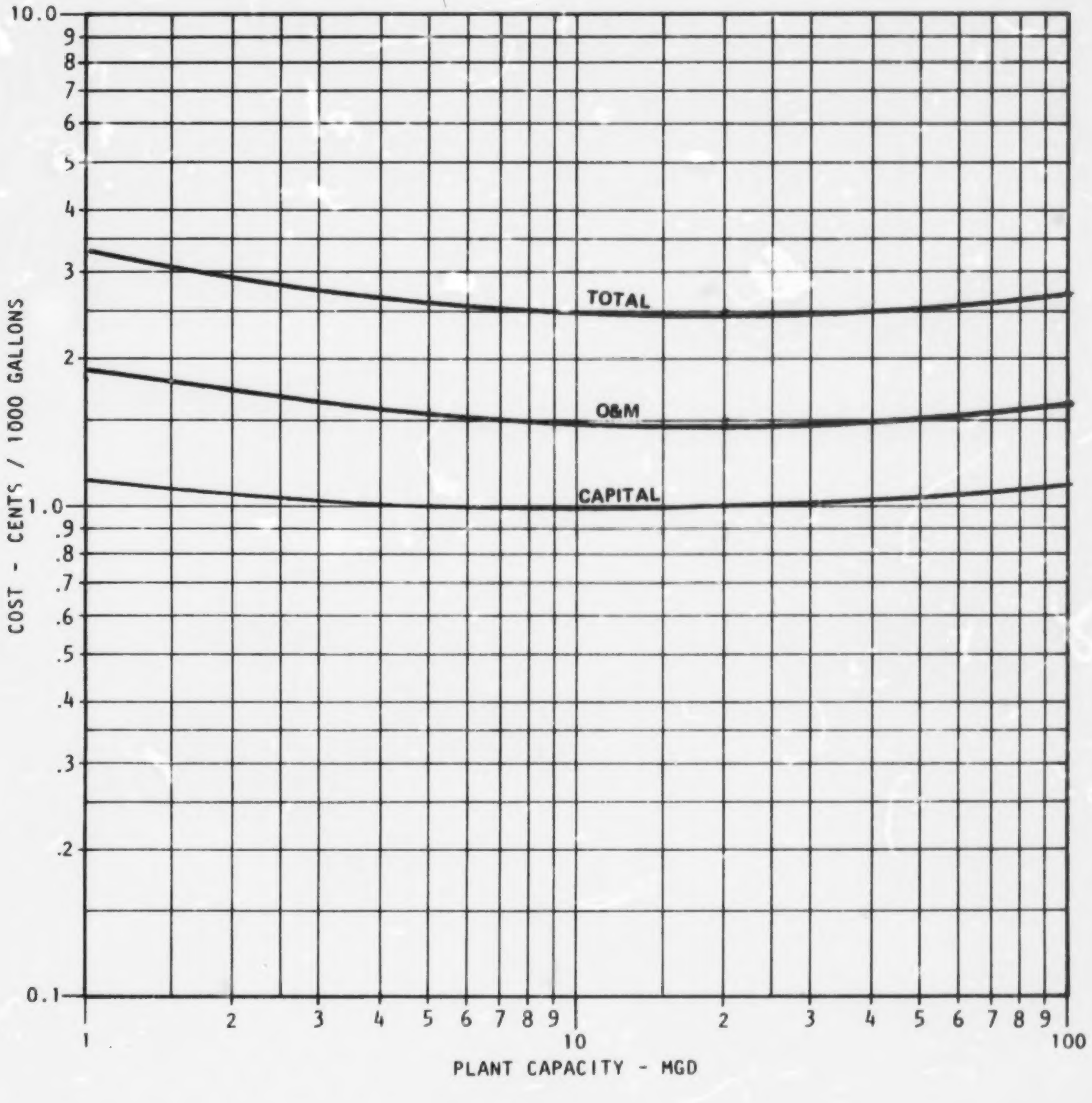
M-2. HEAT TREATMENT

Sludge Influent: Primary Sedimentation + Activated Sludge or High Rate Activated Sludge
A-1 + C-4 or C-5 – Alum or $FeCl_3$ Addition
A-1 + C-7 or C-8
Primary Sedimentation – Alum or $FeCl_3$ Addition + Activated Sludge or Trickling Filter
A-4 + B-3 or C-3
A-5 + B-3 or C-3



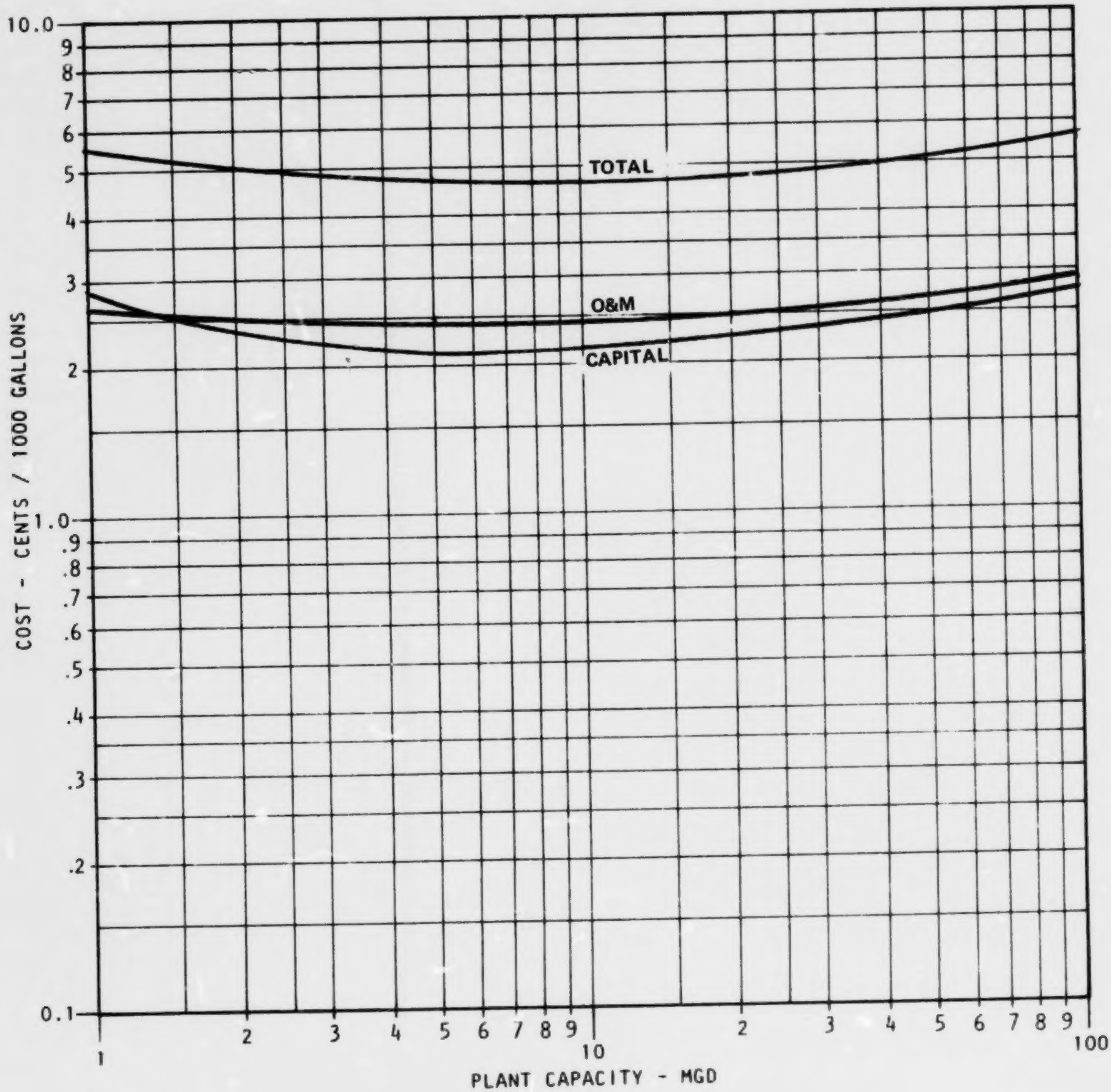
N-1. AIR DRYING

Sludge Influent: Digested Primary + Secondary – Conventional L-1



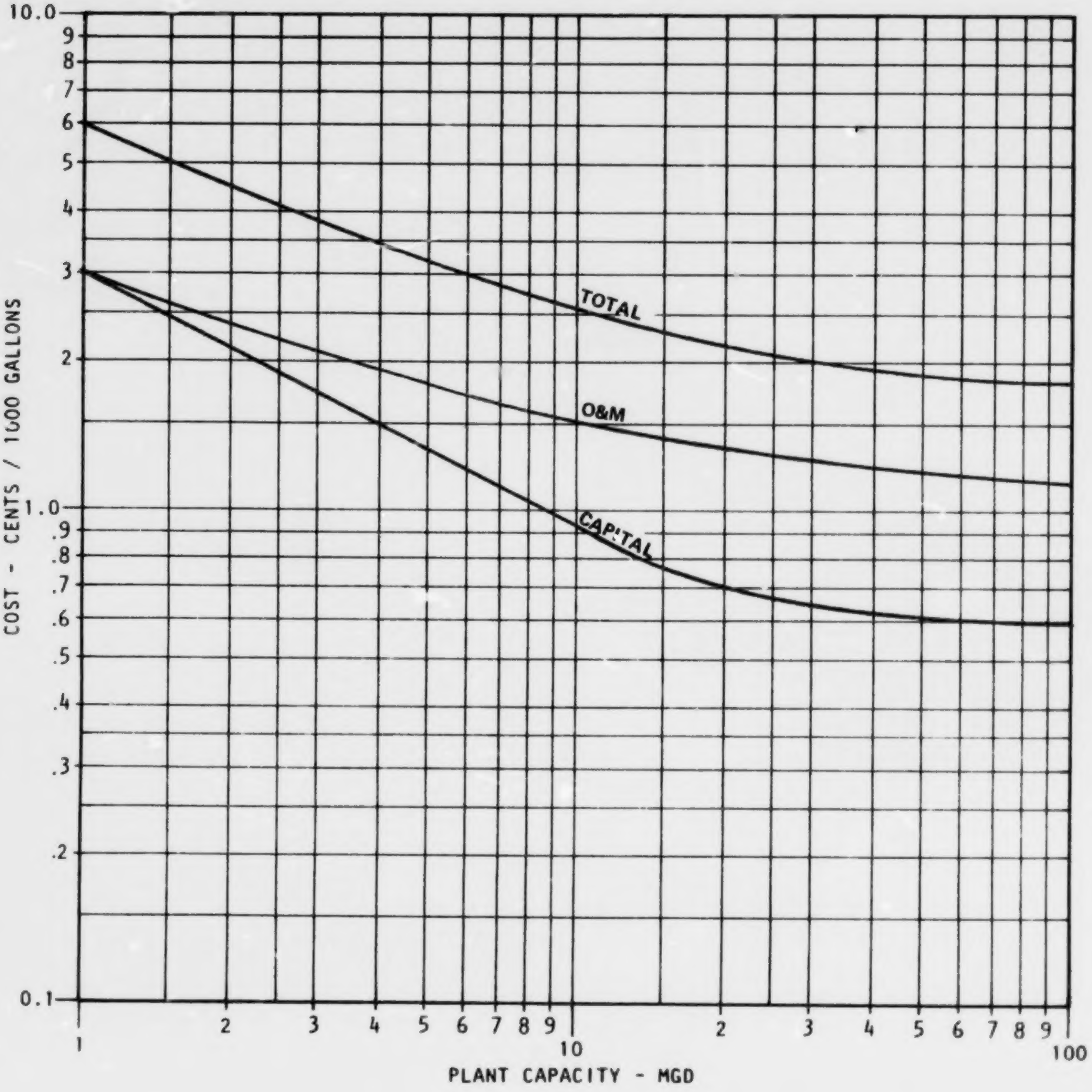
N-2. AIR DRYING

Sludge Influent: Digested Primary + Secondary (Alum or $FeCl_3$ Addition) L-2



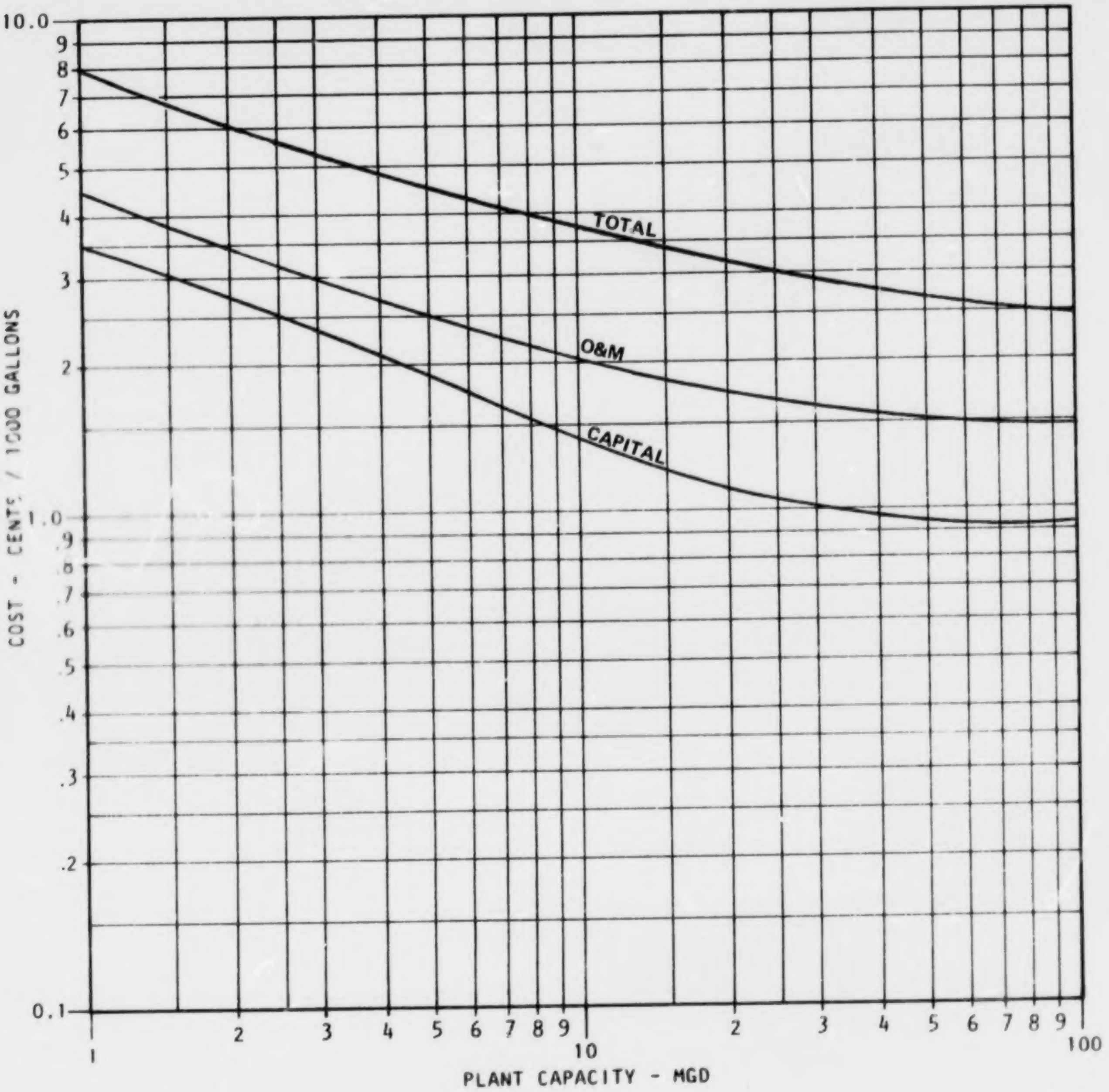
O-1. DEWATERING

Sludge Influent: Primary + Secondary — Conventional or High rate
A-1 + B-1
A-1 + C-1
A-1 + C-6

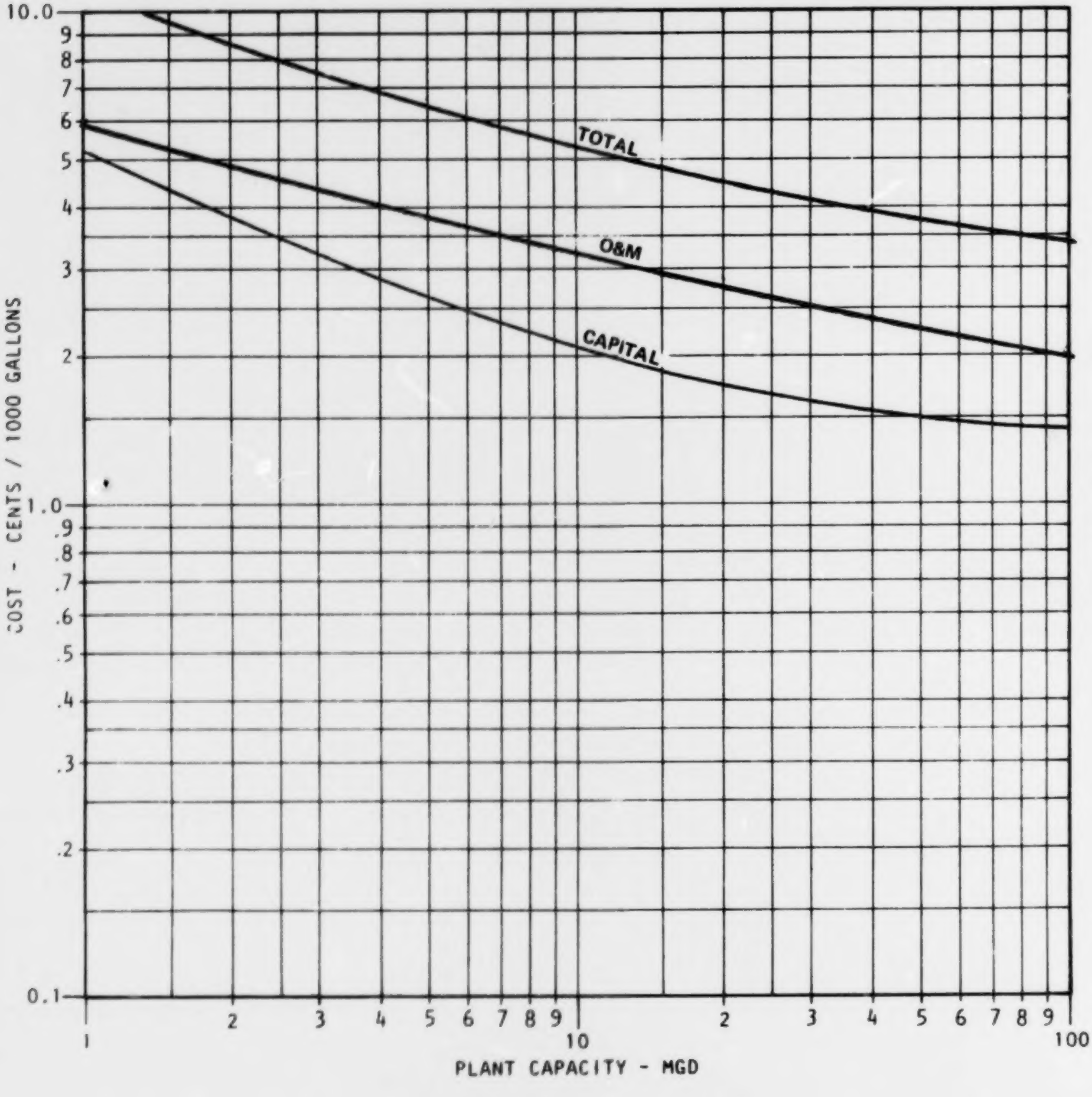


O-2. DEWATERING

Sludge Influent: Primary-Conventional + Secondary-Alum or $FeCl_3$ Addition
A-1 + C-4 or C-5
A-1 + C-7 or C-8
Primary-Alum or $FeCl_3$ Addition + Secondary
A-4 + B-3
A-4 + C-3
A-5 + B-3
A-5 + C-3

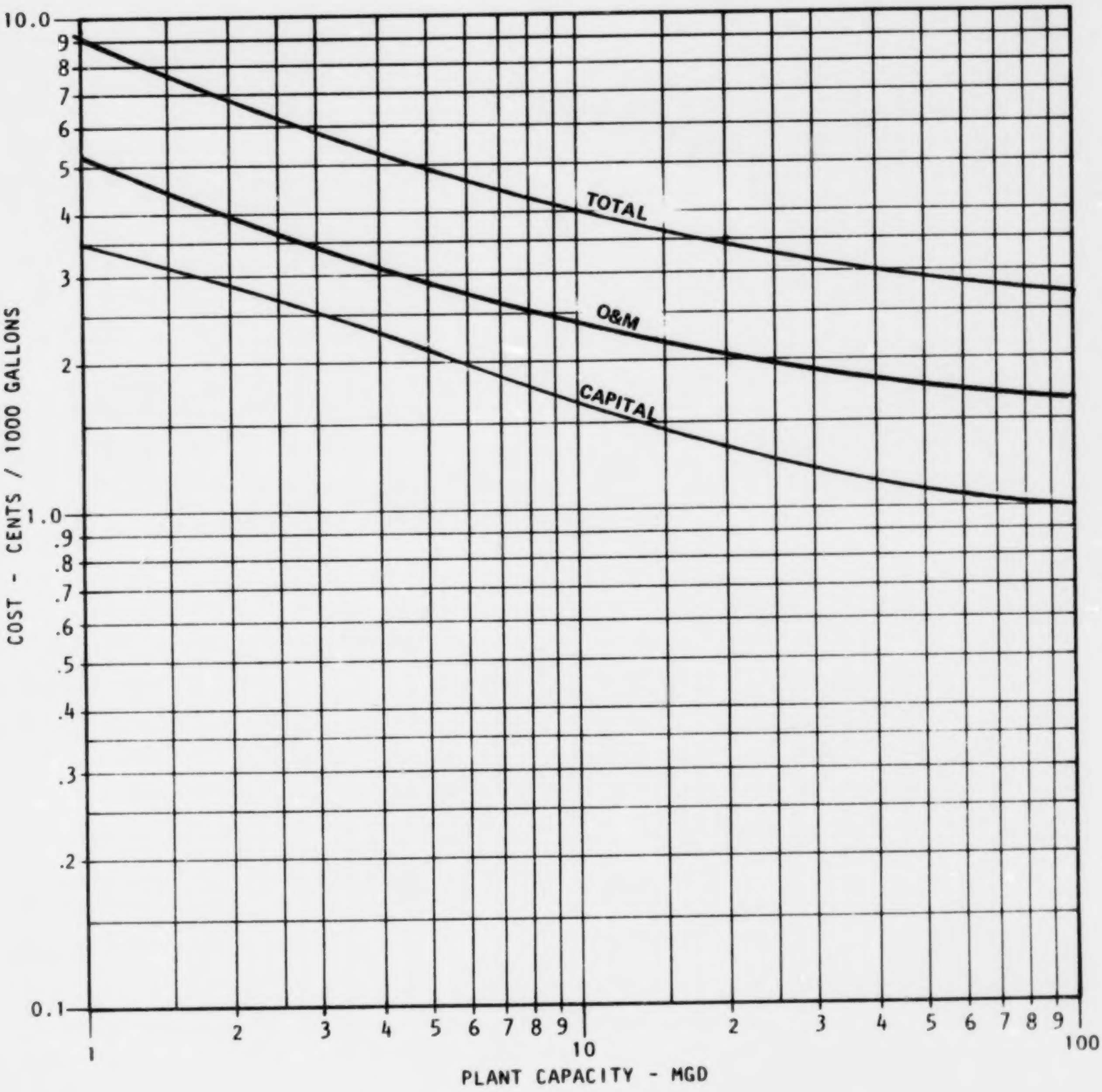


O-3. DEWATERING
Sludge Influent: Primary Sedimentation – Two Stage Lime Addition A-2



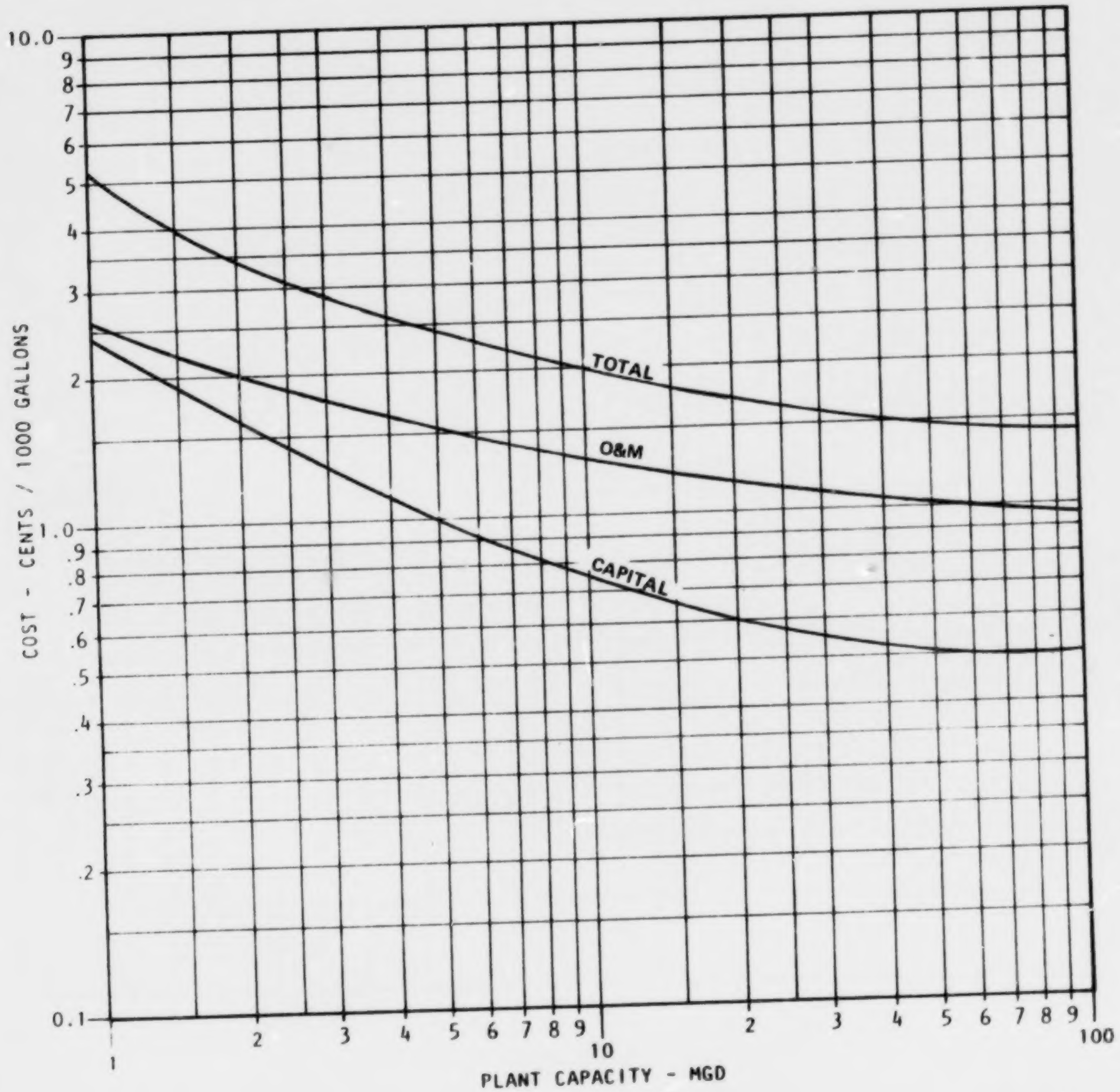
O-4. DEWATERING

Sludge Influent: Primary Sedimentation – Single Stage Lime Addition
+ Trickling Filter or Activated Sludge
A-3 + B-2
A-3 + C-2



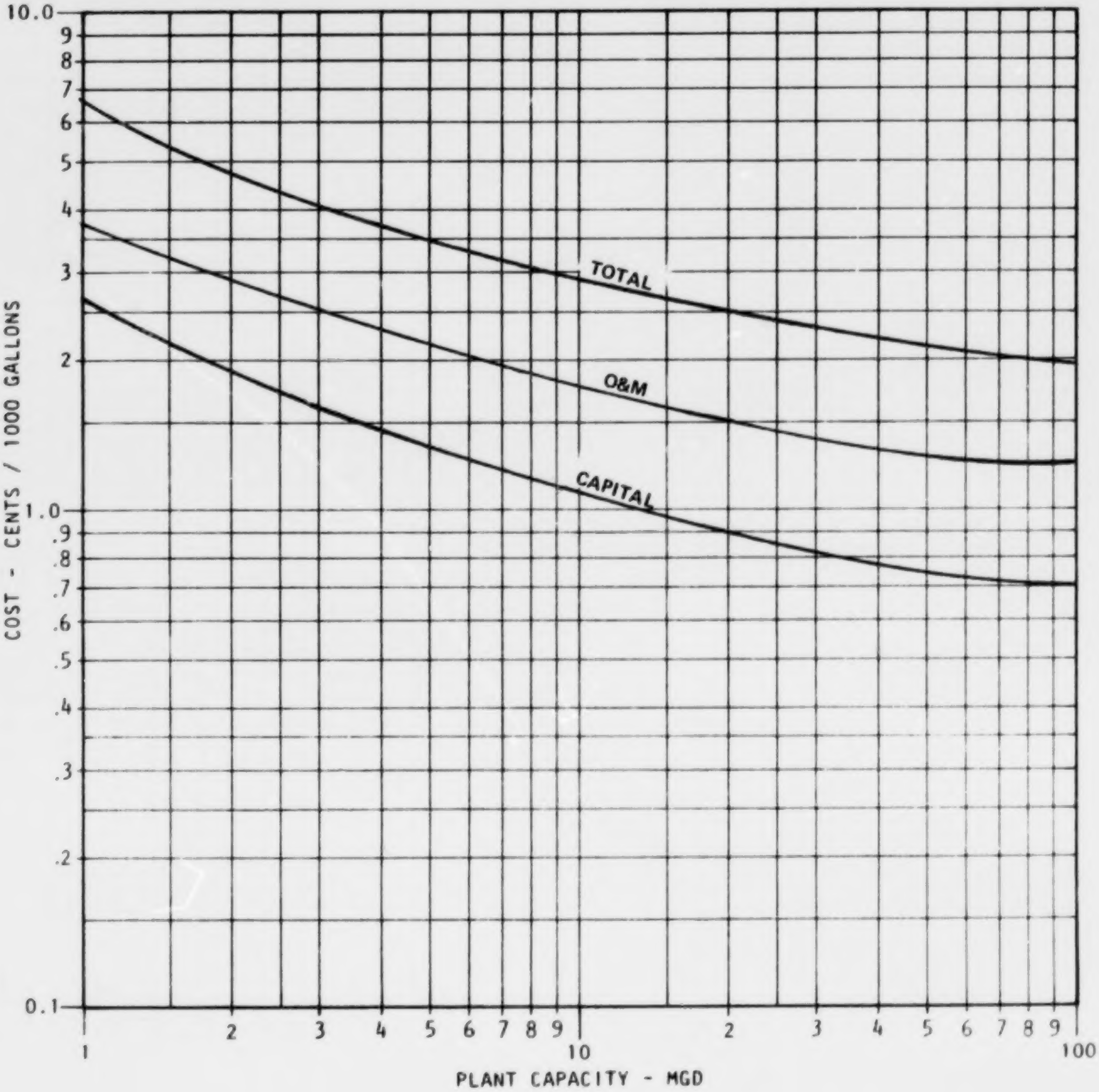
O-5. DEWATERING

Sludge Influent: Digested Primary + Secondary – Conventional (L-1)

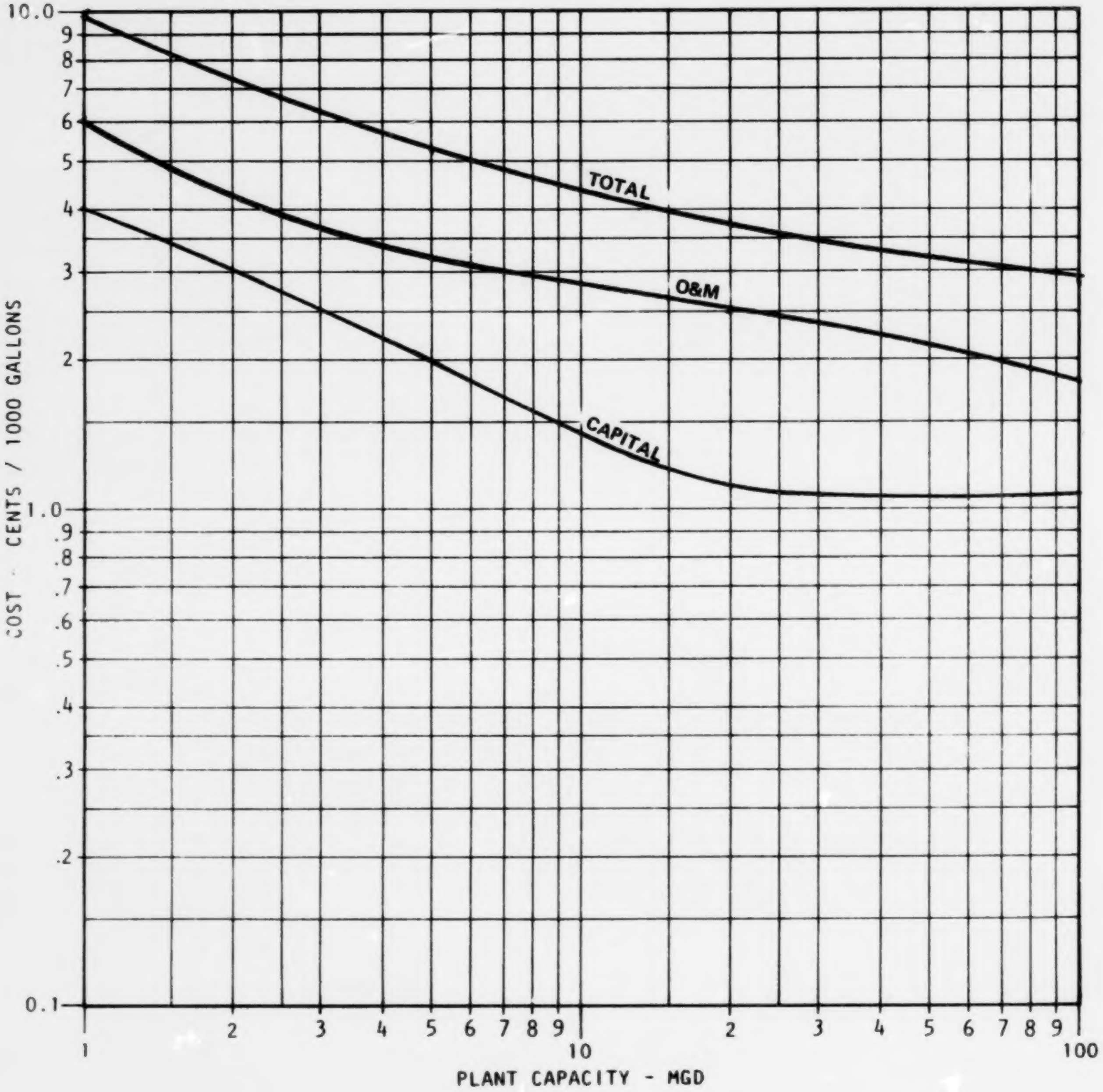


O-6. DEWATERING

Sludge Influent: Digested Primary + Secondary (Alum or $FeCl_3$ Addition) (L-2)

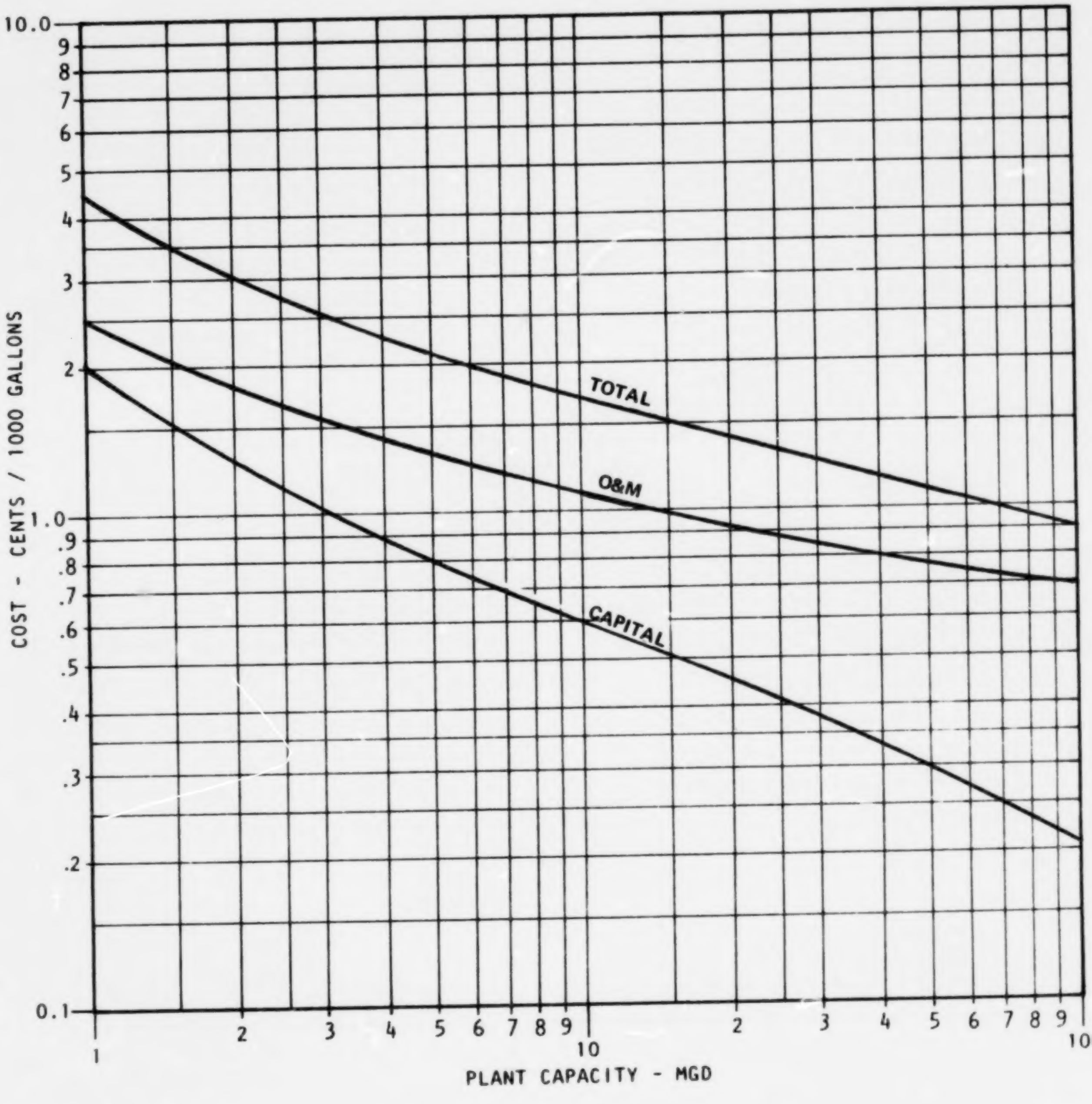


O-7. DEWATERING
Sludge Influent: Two-Stage Tertiary Lime Treatment F-1
F-2



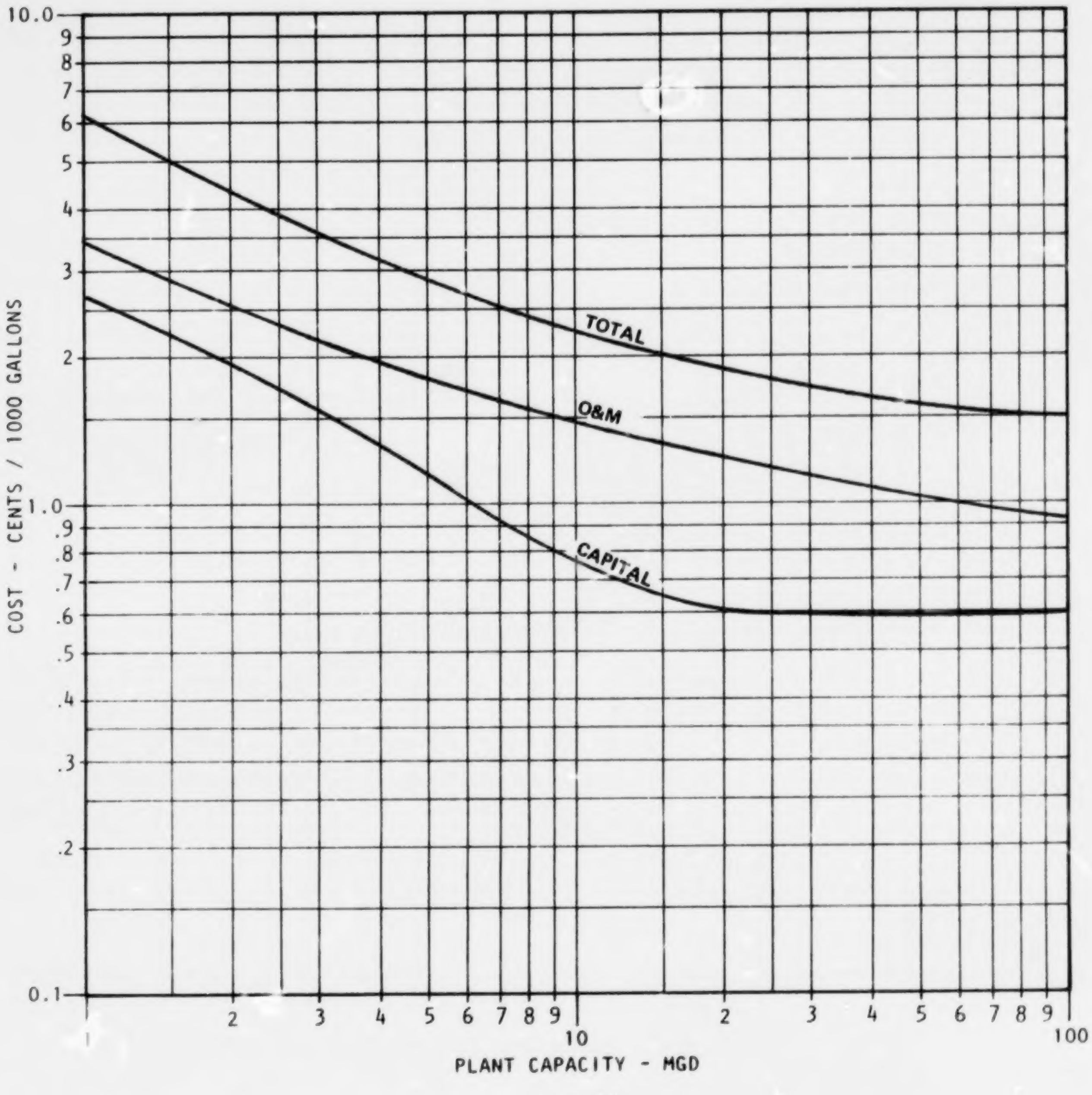
O-8. DEWATERING

Sludge Influent: Heat-Treated Primary + Secondary – Conventional M-1

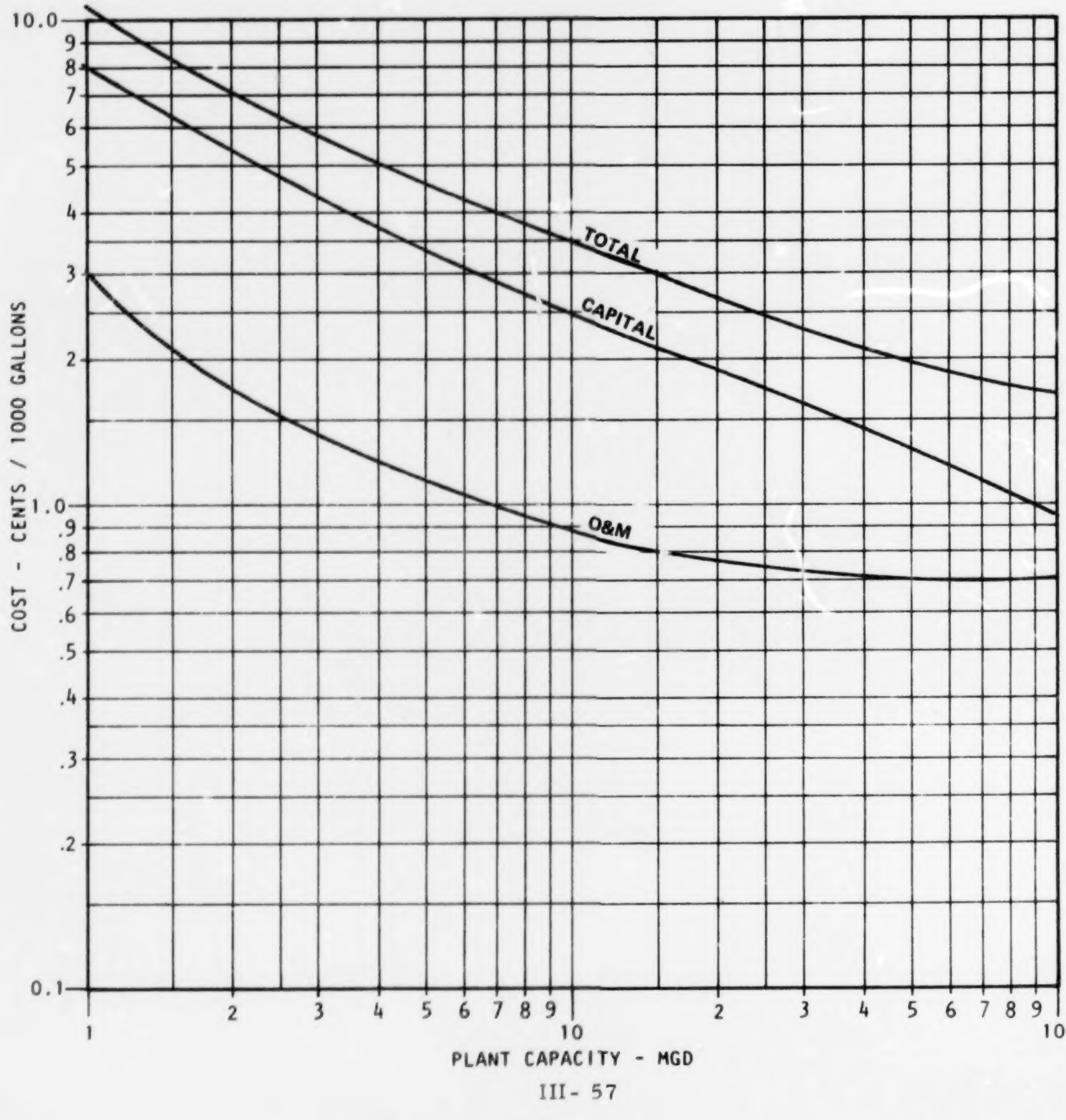


O-9. DEWATERING

Sludge Influent: Heat Treated Primary + Secondary (Alum or $FeCl_3$ Addition) M-2

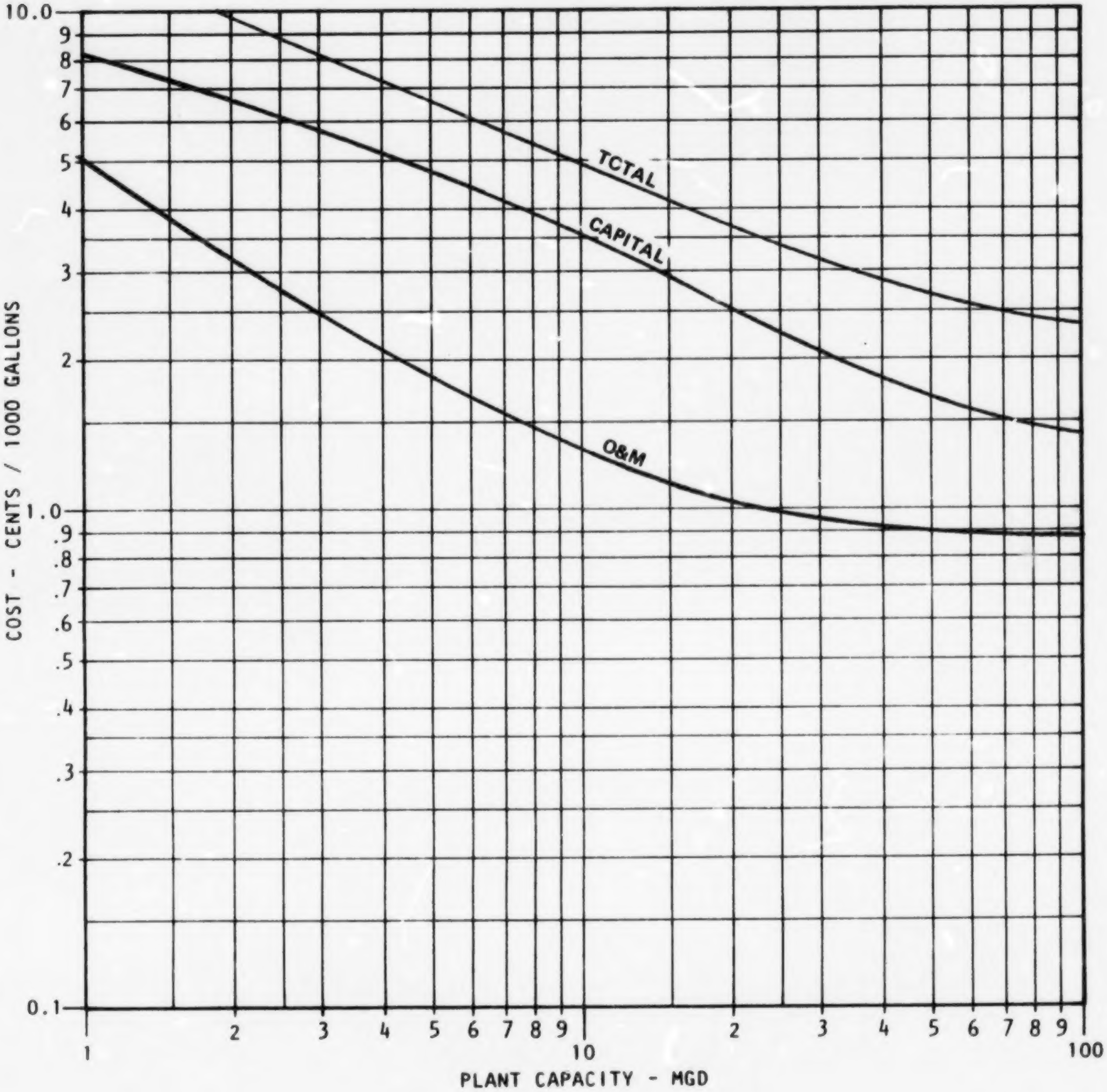


P-1. INCINERATION
Sludge Influent: Dewatered Primary + Secondary – Conventional 0-1



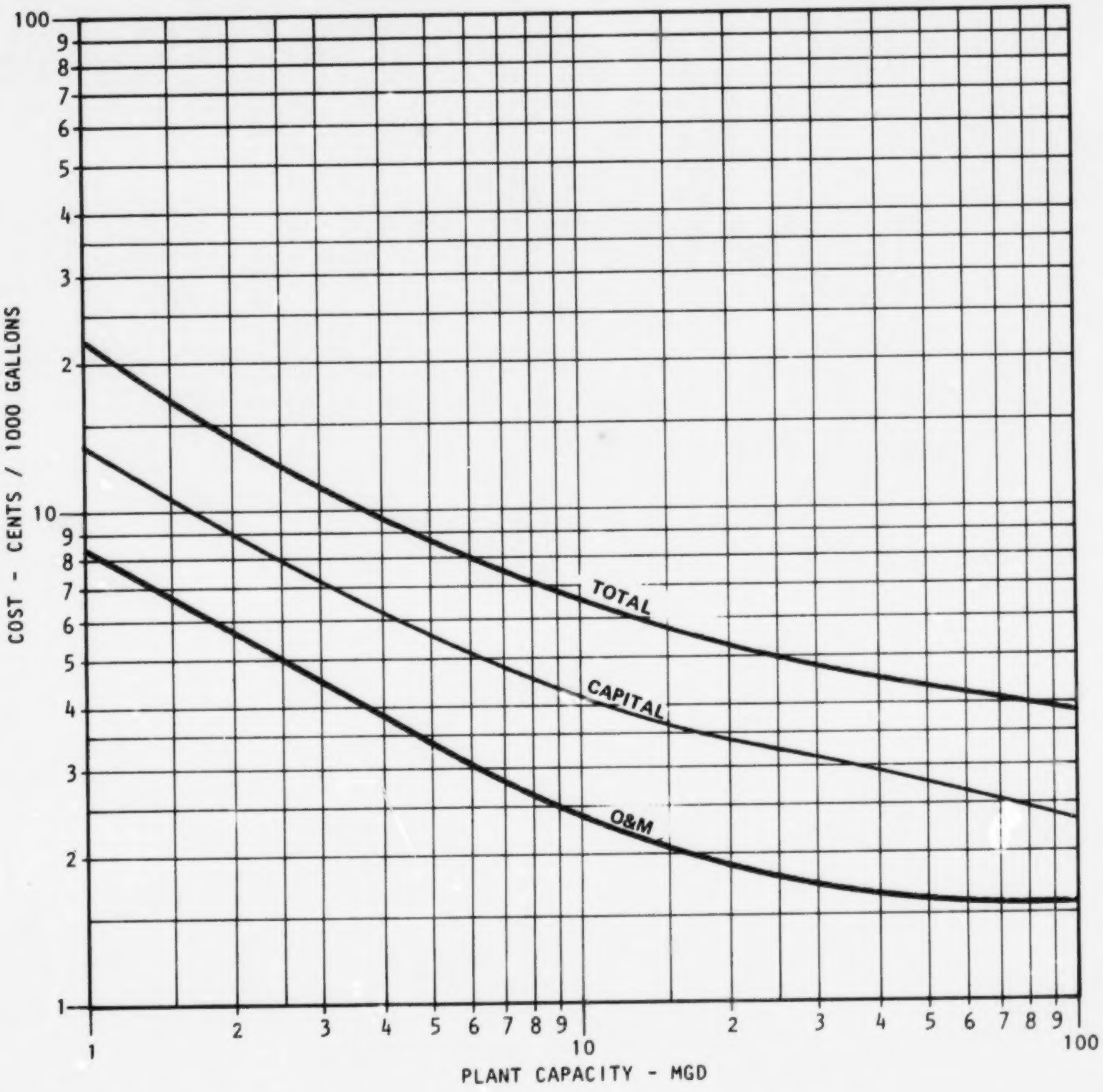
P-2. INCINERATION

Sludge Influent: Dewatered Primary + Secondary
(Alum or $FeCl_3$ Addition) 0-2



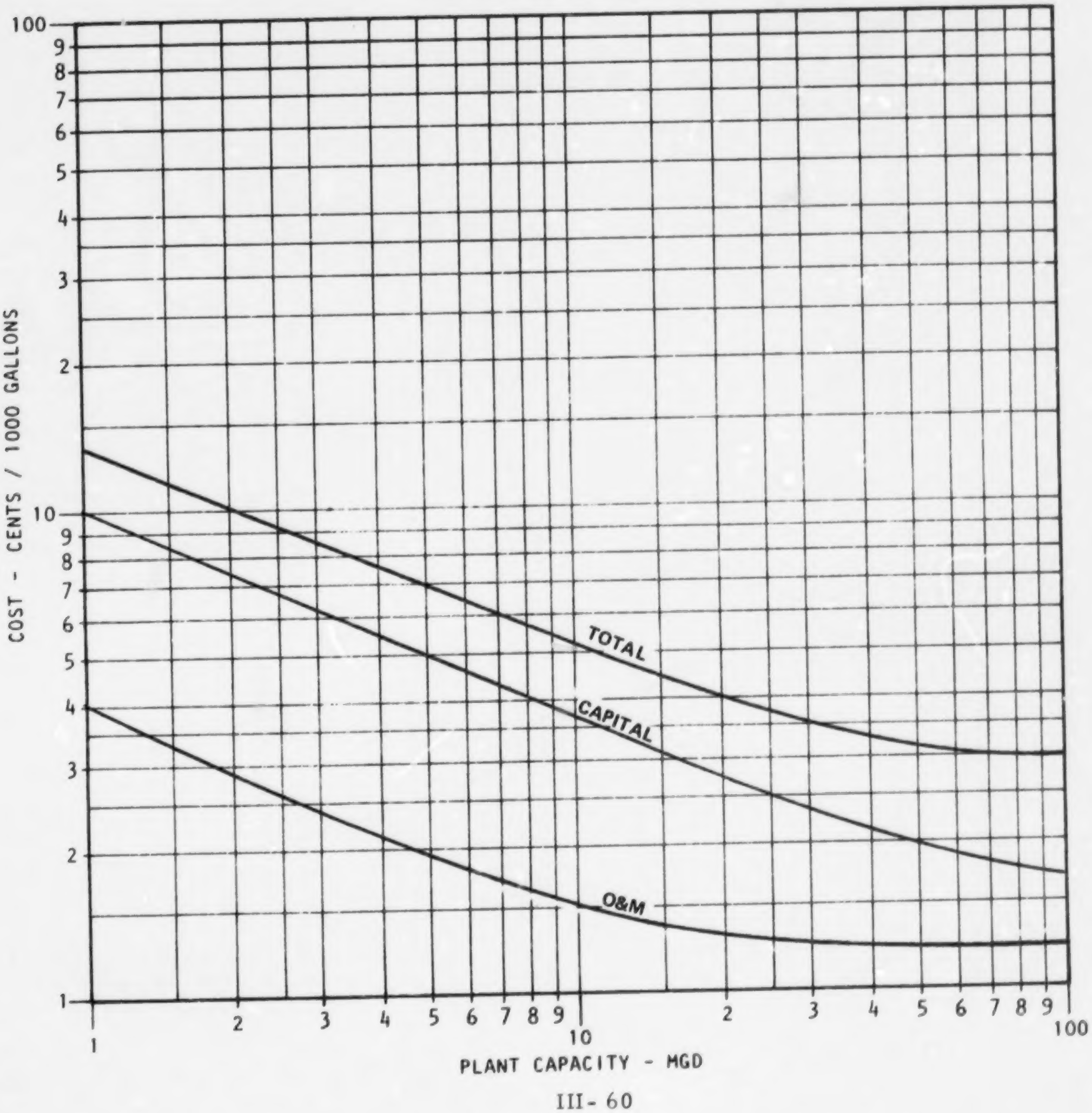
P-3. INCINERATION

Sludge Influent: Primary Sedimentation – Two-Stage Lime Addition O-3



P-4. INCINERATION

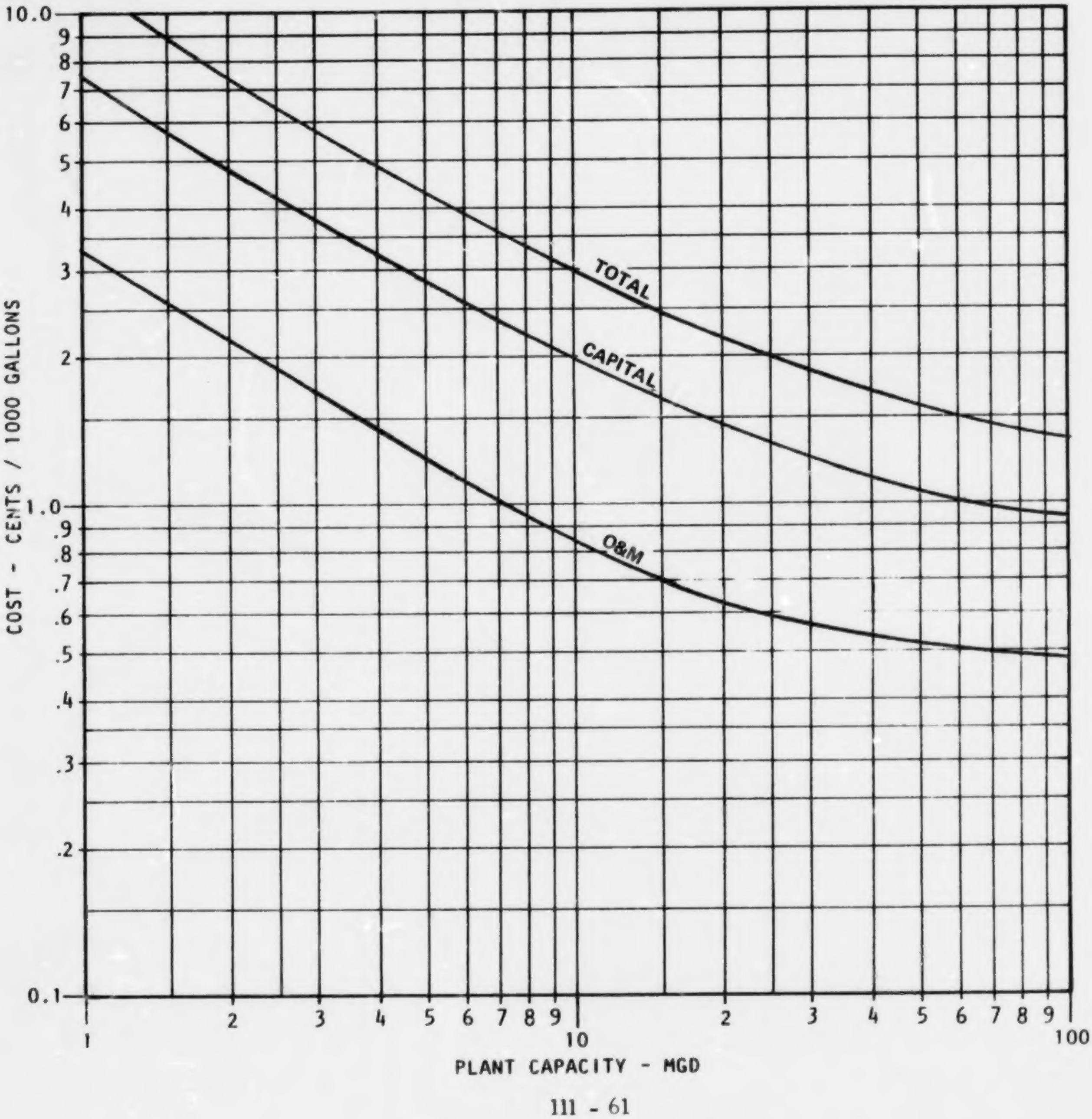
Sludge Influent: Dewatered Primary Sedimentation – Single Stage Lime Addition 0-4



P-5. INCINERATION

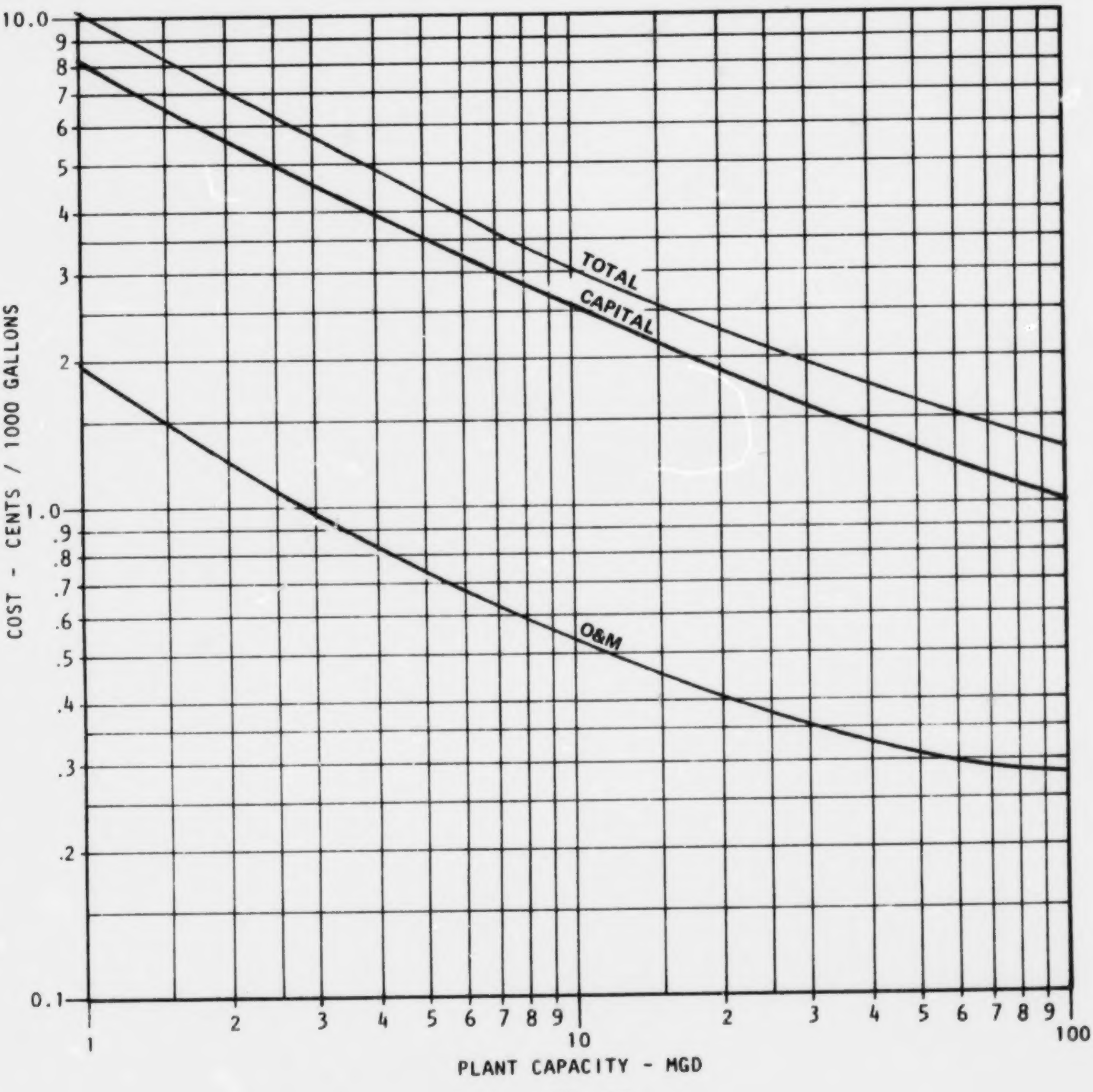
Sludge Influent: **Dewatered Tertiary Two-Stage Lime Treated + Dewatered Primary and Secondary — Conventional**

O-7 + O-1



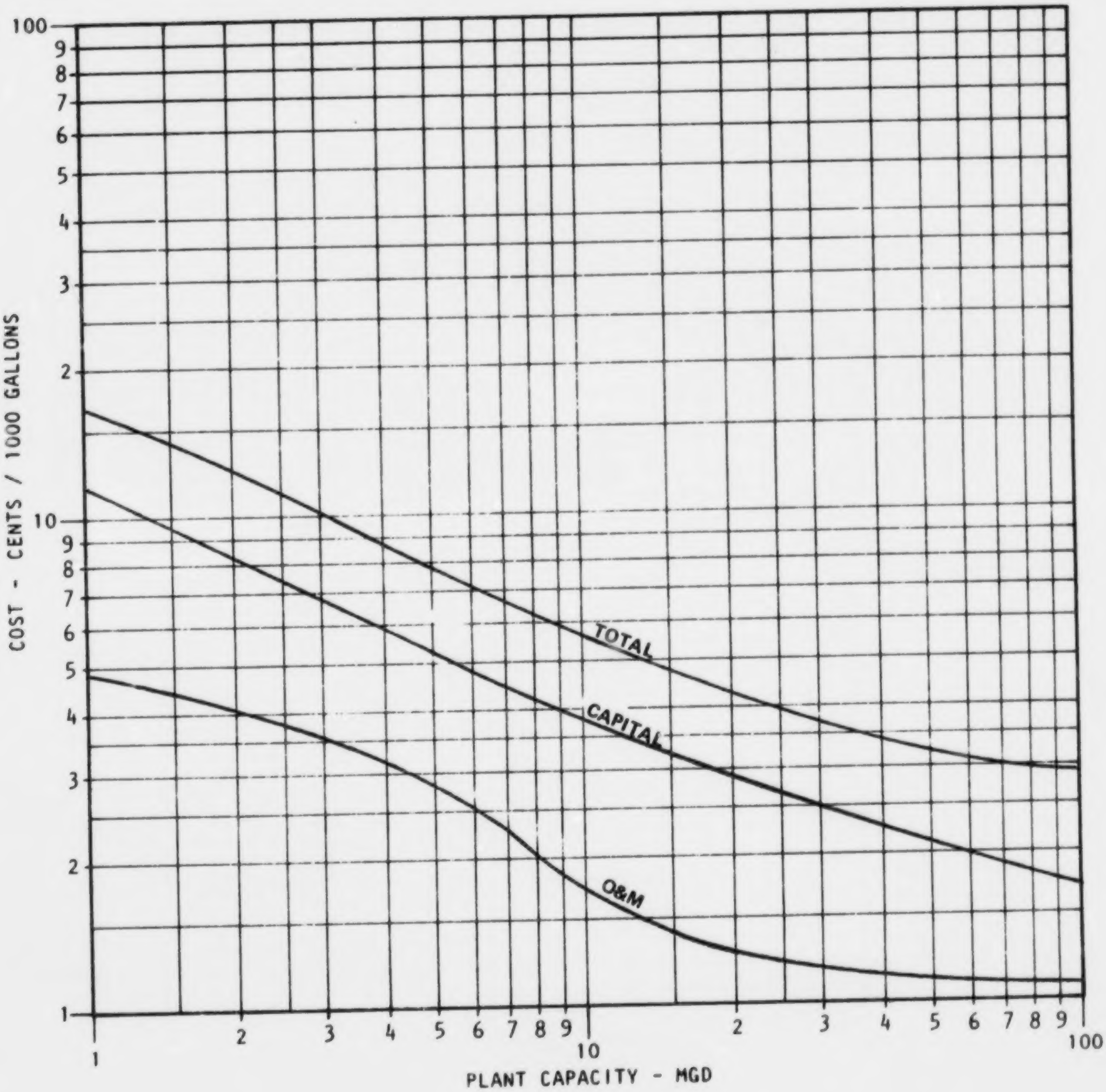
P-6. INCINERATION

Sludge Influent: Dewatered Heat-Treated Primary + Secondary – Conventional O-8



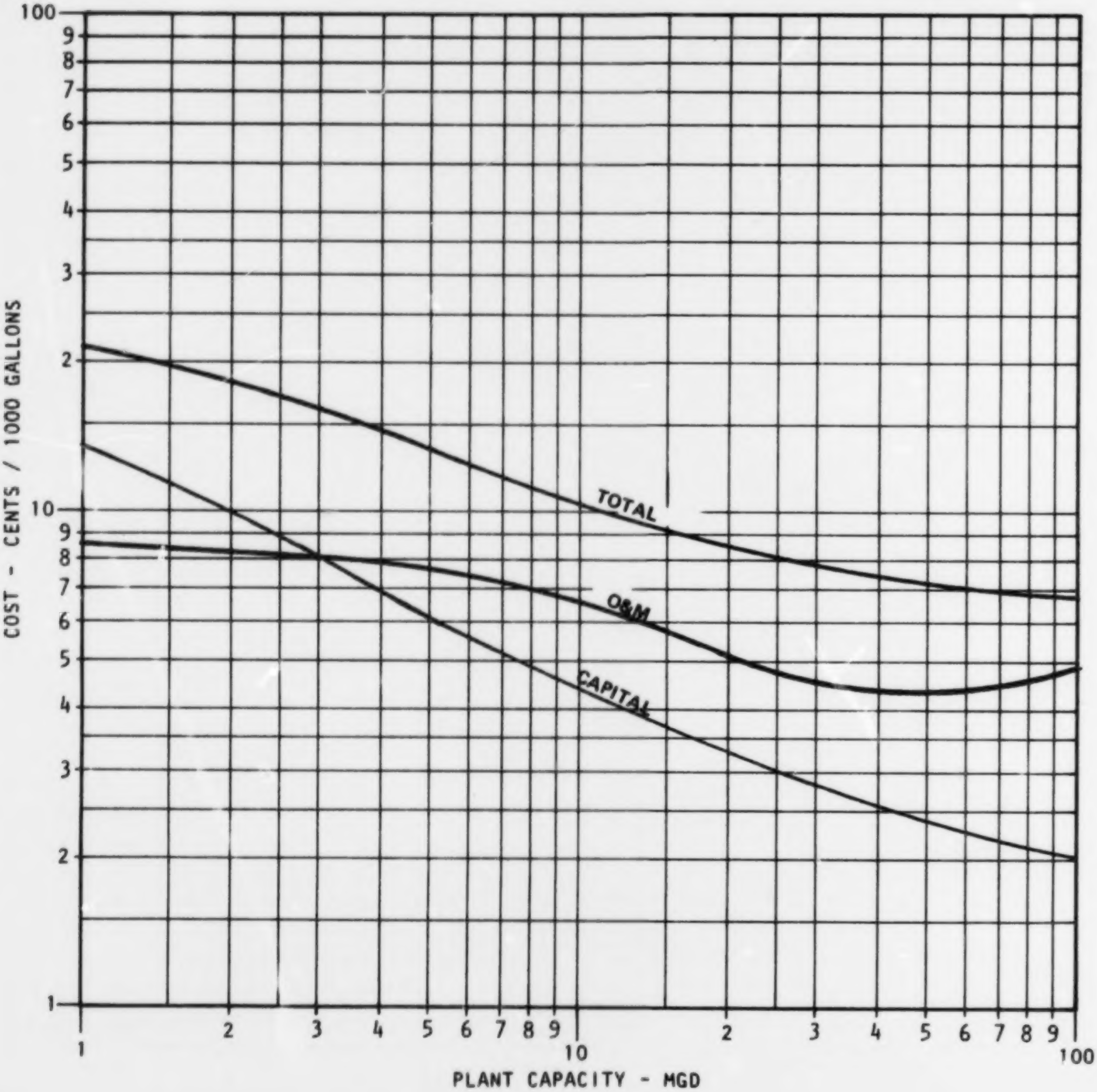
P-7. INCINERATION

Sludge Influent: Dewatered Heat-Treated Primary + Secondary (Alum + $FeCl_3$ Addition) O-9



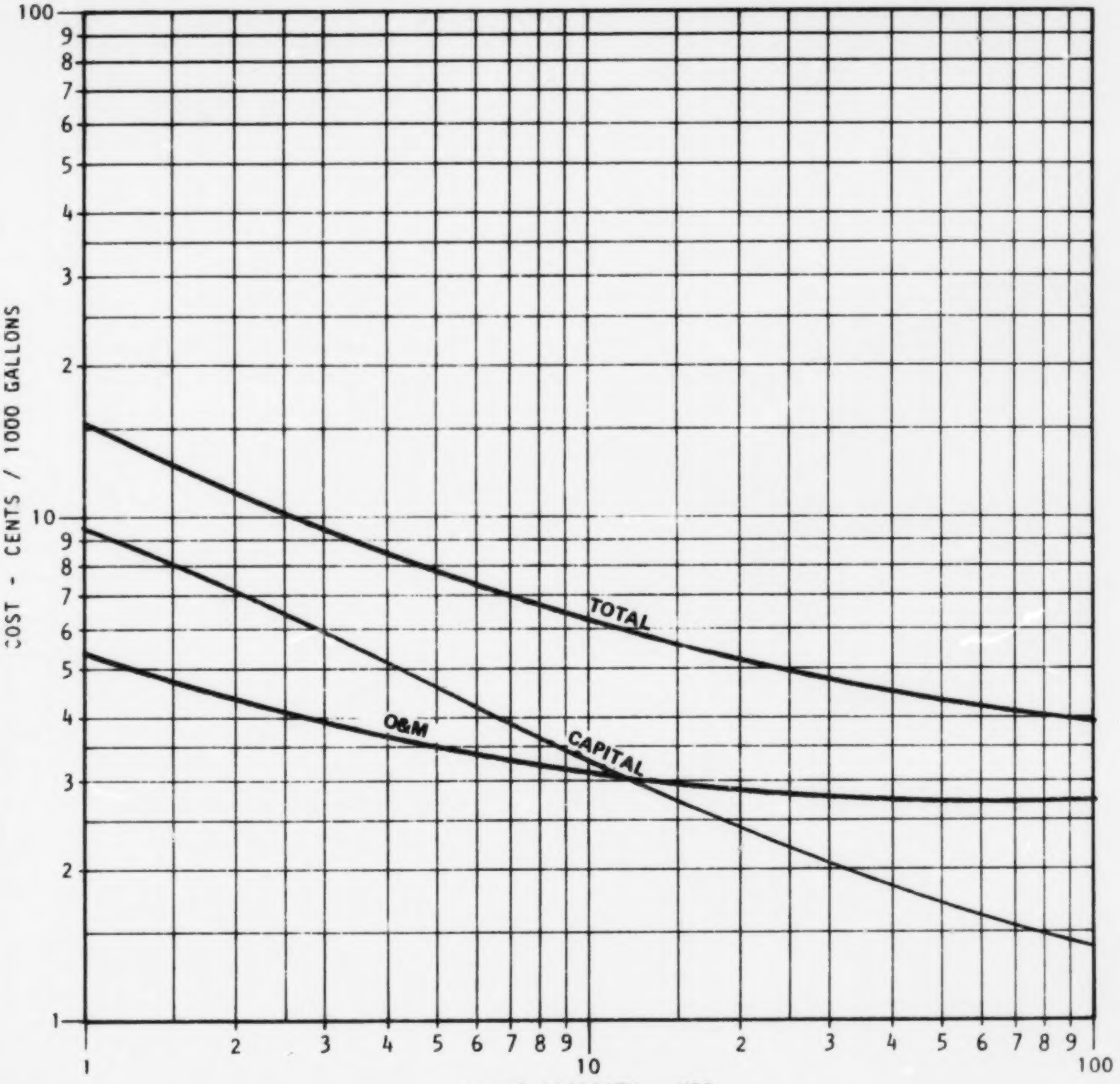
Q-1. RECALCINATION

Influent: Dewatered Sludge From Two-Stage Lime Addition in Primary (O-3)



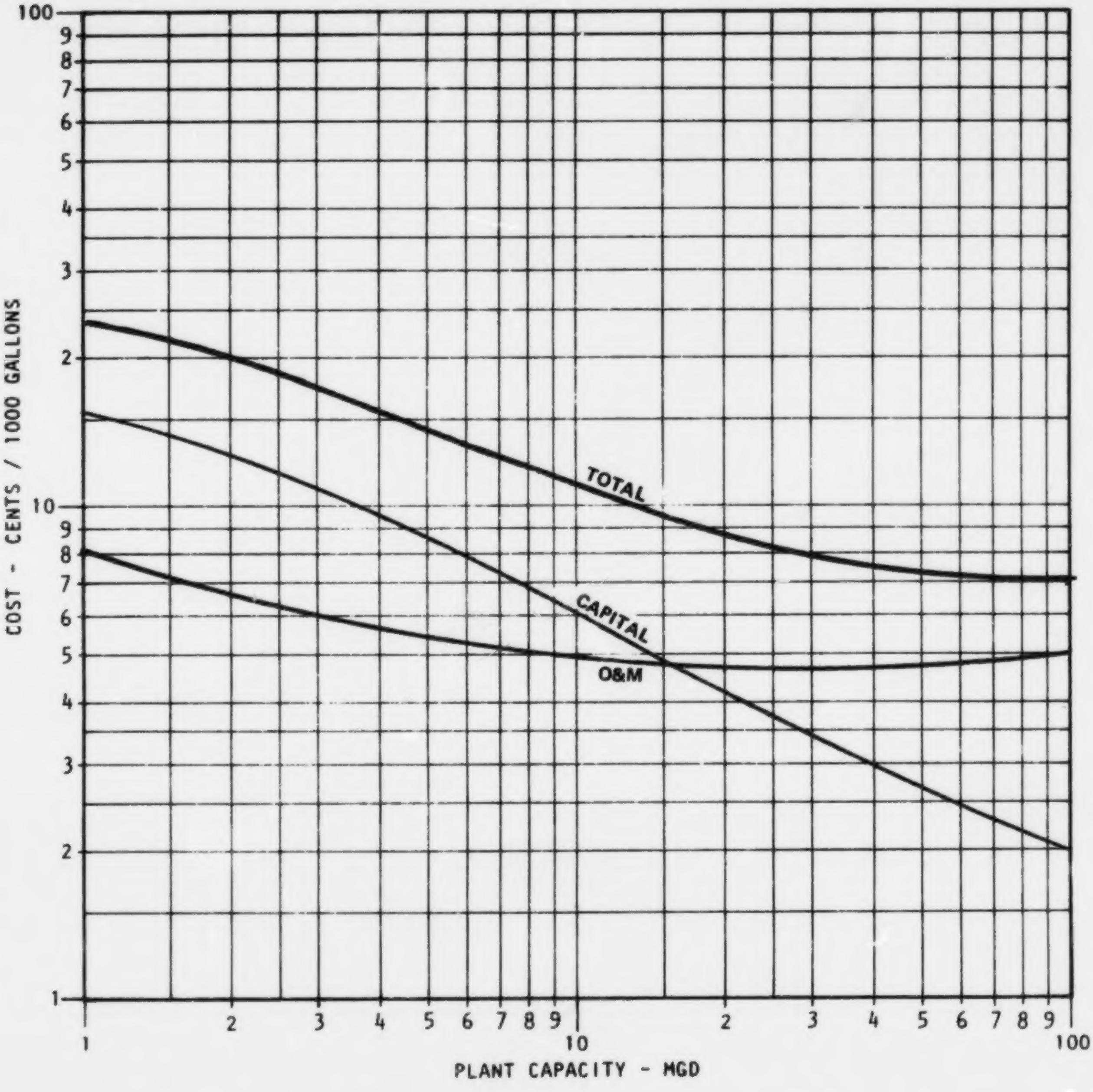
Q-2. RECALCINATION

Influent: Dewatered Sludge from Single Stage Lime Addition in Primary Sedimentation + Sludge From Secondary Treatment
(O-4)



Q-3. RECALCINATION

Influent: Dewatered Sludge From – Two-Stage Tertiary Lime Treatment (O-7)



Section IV-Combining Unit Processes for Viable Wastewater Treatment Systems

4.1 - Definition

The unit processes described by the flow sheets appended to Section II can be combined in a variety of logical sequences to make up viable wastewater treatment and sludge handling systems. Varying degrees of effuent quality can be achieved depending upon the choice of combinations.

4.2 - Combined Unit Process Diagrams

Logical combinations of the unit processes are shown by means of Diagrams IV-1 and IV-2. The combinations are limited to those which by experience have proven to be effective in achieving intended levels of treatment. Diagram IV-1 presents combinations of wastewater treatment unit processes and Diagram IV-2 presents sludge handling unit process combinations.

Unit processes are given letter and numerical designations, the same as noted on the unit process flow sheets in Section II and cost curves in Section III. Descriptions of unit processes are included in the left hand column of the Diagrams. Unit processes in Diagram IV-1 are connected by lined pathways to form various complete wastewater treatment systems. Generally, by beginning at the innermost unit processes (primary sedimentation with or without chemical addition), and proceeding radially outward along the various pathways to subsequent unit processes, progressively higher levels of treatment are noted. The pathways need not be followed to the end, but can be terminated at various intermediate processes depending upon the degree of treatment desired. It is important to note that, although disinfection has not been shown on Diagram IV-1, it has been assumed to be the final unit process in any treatment system. The effluent quality expected from each system is shown on the same circumferential line of the last unit process preceding disinfection. Each unit process which could logically precede disinfection in a combined system is located on a circumferential line. In addition to disinfection, preliminary treatment and raw wastewater pumping have not been shown on Diagram IV-1 for reasons explained in Section V.

Alternative sludge handling systems are presented in Diagram IV-2. The inner portion of this diagram is similar to Diagram IV-1, but depicts only unit processes which produce sludges. The outer portion of the diagram shows combined sludge handling systems capable of handling the sludges produced. By following the pathways outward, alternative systems can be found which are capable of handling sludges produced by unit processes in each wastewater treatment system. The pathways can be terminated at intermediate processes as in Diagram IV-1. The final disposal requirements or alternatives are shown in the upper portion of the diagram, located on the same circumferential line of the final sludge handling unit process in any system chosen.

A detailed description of how to use these two diagrams in comparing cost-effectiveness of alternative wastewater treatment systems, including three examples, follows in Section V.

WASTEWATER TREATMENT UNIT PROCESSES

AA. Preliminary Treatment
Influent: Raw wastewater

AB. Raw Wastewater Pumping
Influent: Effluent from AA

A. Primary Sedimentation
Influent: Effluent from AA or AB
- A-1 Conventional
- A-2 Two-Stage Lime Addition
- A-3 Single Stage Lime Addition
- A-4 Alum Addition
- A-5 $FeCl_3$ Addition

B. Trickling Filter
- B-1 Influent: Effluent from A-1
- B-2 Influent: Effluent from A-3
- B-3 Influent: Effluent from A-4 or A-5

C. Activated Sludge
- C-1 Conventional
  Influent: Effluent from A-1
- C-2 Conventional
  Influent: Effluent from A-3
- C-3 Conventional
  Influent: Effluent from A-4 or A-5
- C-4 Alum Addition
  Influent: Effluent from A-1
- C-5 $FeCl_3$ Addition
  Influent: Effluent from A-1
- C-6 High Rate
  Influent: Effluent from A-1
- C-7 High Rate & Alum Addition
  Influent: Effluent from A-1
- C-8 High Rate & $FeCl_3$ Addition
  Influent: Effluent from A-1

D. Filtration
Influent: Effluent from A-2, B-2, B-3, C-2,
C-3, C-4, C-5, F-1 or F-2
G-1, G-2, G-3, G-4, H, J, K

E. Activated Carbon
Influent: Effluent from D

F. Two-Stage Tertiary Lime Treatment
- F-1 Influent: Effluent from B-1
- F-2 Influent: Effluent from C-1

G. Biological Nitrification
- G-1 Influent: Effluent from C-6
- G-2 Influent: Effluent from B-1
- G-3 Influent: Effluent from A-3, A-4 or A-5
- G-4 Influent: Effluent from A-2, C-7 or C-8

H. Biological Denitrification
Influent: Effluent from G-1, G-2, G-3 or G-4

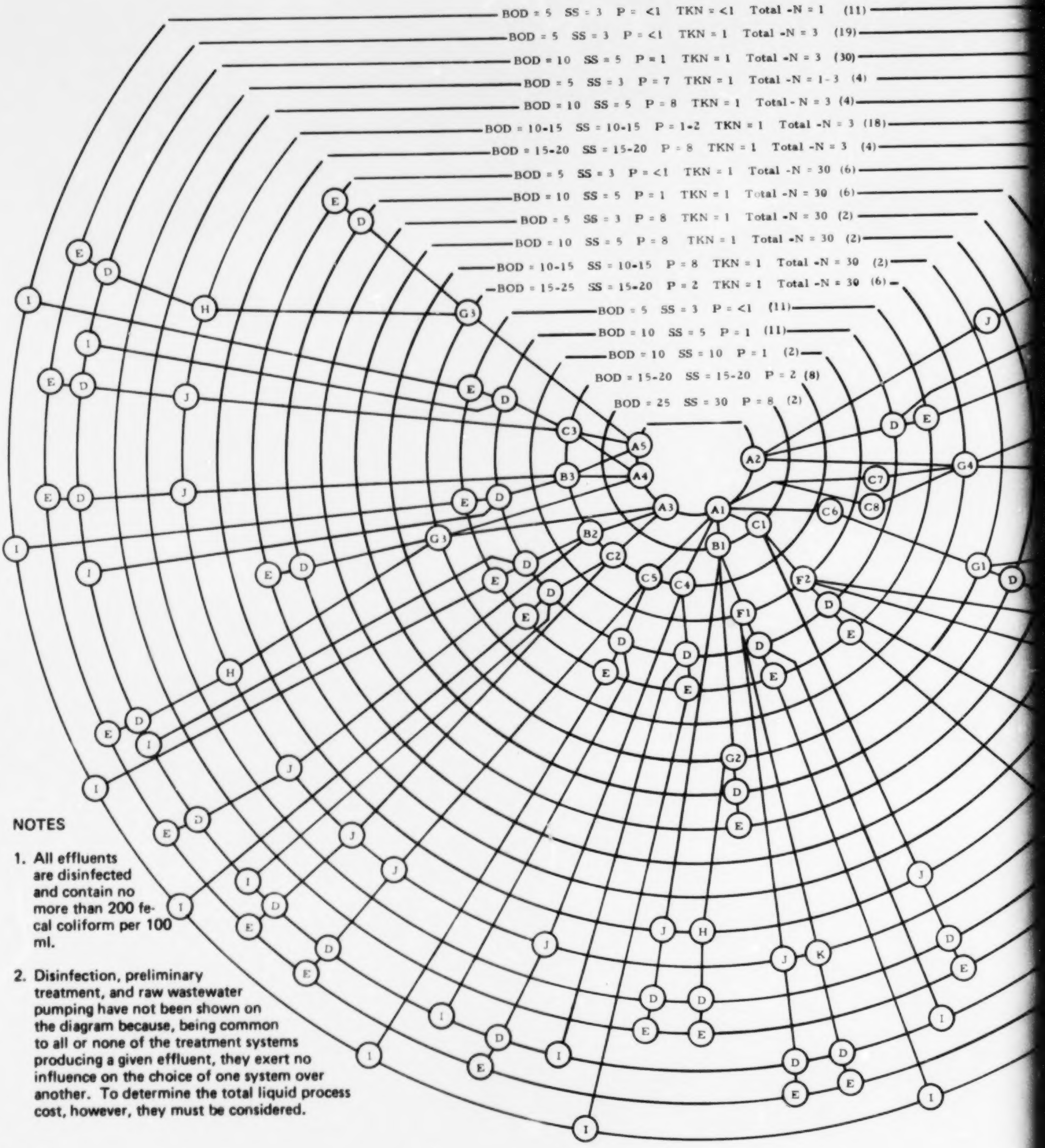
I. Ion Exchanges
Associated with A-2, B-2, B-3, C-2, C-3, C-4,
C-5, F-1, or F-2

J. Breakpoint Chlorination
Influent: Effluent from A-2, B-1, B-2, B-3, C-1, C-2,
C-3, C-4, C-5, F-1 or F-2

K. Ammonia Stripping
Influent: Effluent from F-1 or F-2

R. Disinfection
Influent: Effluent from any treatment process

a


BOD = 5 SS = 3 P = <1 TKN = <1 Total -N = 1 (11)
BOD = 5 SS = 3 P = <1 TKN = 1 Total -N = 3 (19)
BOD = 10 SS = 5 P = 1 TKN = 1 Total -N = 3 (30)
BOD = 5 SS = 3 P = 7 TKN = 1 Total -N = 1-3 (4)
BOD = 10 SS = 5 P = 8 TKN = 1 Total - N = 3 (4)
BOD = 10-15 SS = 10-15 P = 1-2 TKN = 1 Total -N = 3 (18)
BOD = 15-20 SS = 15-20 P = 8 TKN = 1 Total -N = 3 (4)
BOD = 5 SS = 3 P = <1 TKN = 1 Total -N = 30 (6)
BOD = 10 SS = 5 P = 1 TKN = 1 Total -N = 30 (6)
BOD = 5 SS = 3 P = 8 TKN = 1 Total -N = 30 (2)
BOD = 10 SS = 5 P = 8 TKN = 1 Total -N = 30 (2)
BOD = 10-15 SS = 10-15 P = 8 TKN = 1 Total -N = 30 (2)
BOD = 15-25 SS = 15-20 P = 2 TKN = 1 Total -N = 30 (6)
BOD = 5 SS = 3 P = <1 (11)
BOD = 10 SS = 5 P = 1 (11)
BOD = 10 SS = 10 P = 1 (2)
BOD = 15-20 SS = 15-20 P = 2 (8)
BOD = 25 SS = 30 P = 8 (2)
A1
A2
A3
A4
A5
B1
B2
B3
C1
C2
C3
C4
C5
C6
C7
C8
D
E
F1
F2
G1
G2
G3
G4
H
I
J
K

NOTES

1. All effluents are disinfected and contain no more than 200 fecal coliform per 100 ml.

2. Disinfection, preliminary treatment, and raw wastewater pumping have not been shown on the diagram because, being common to all or none of the treatment systems producing a given effluent, they exert no influence on the choice of one system over another. To determine the total liquid process cost, however, they must be considered.

b

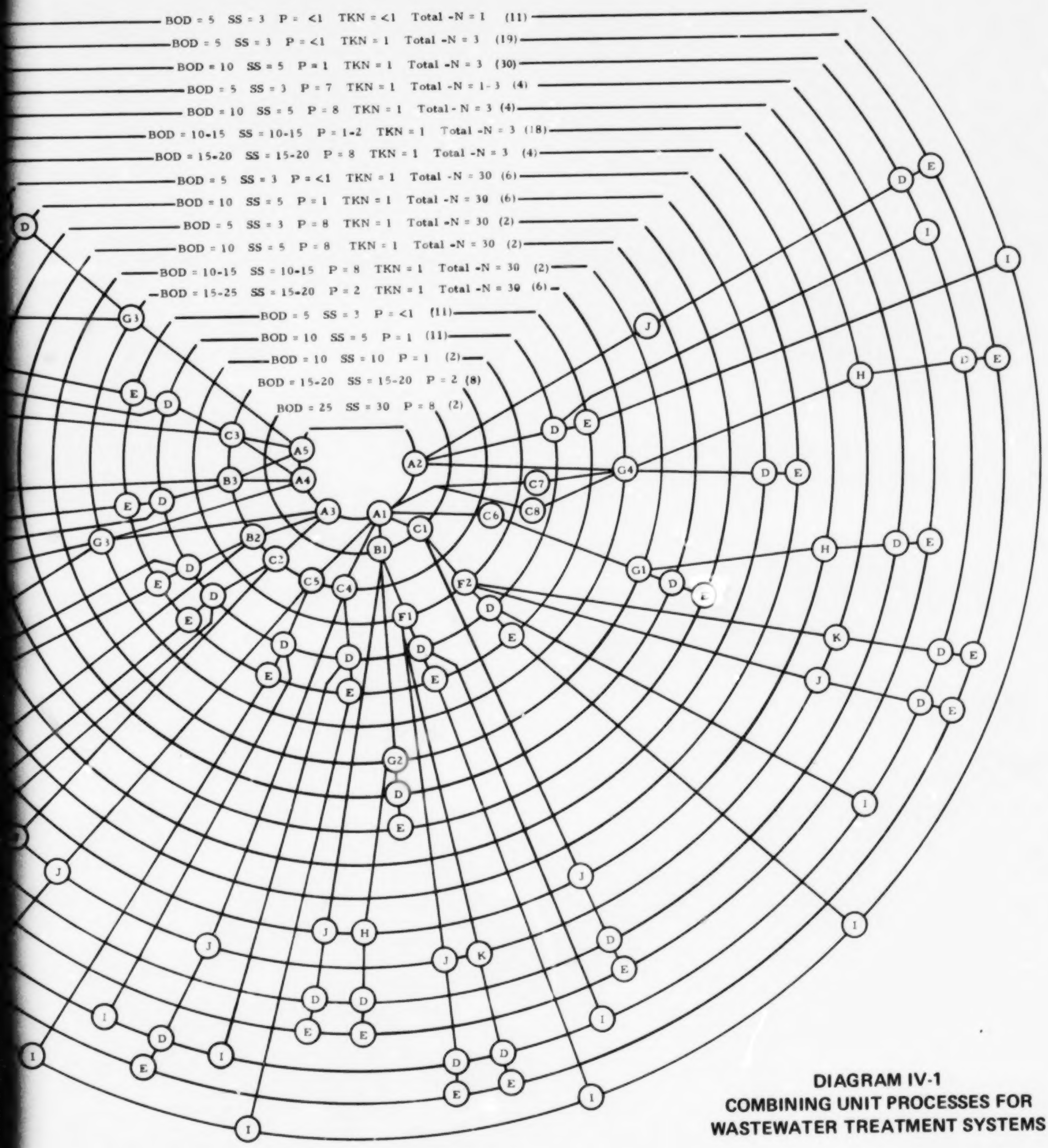

BOD = 5 SS = 3 P = <1 TKN = <1 Total -N = 1 (11)
BOD = 5 SS = 3 P = <1 TKN = 1 Total -N = 3 (19)
BOD = 10 SS = 5 P = 1 TKN = 1 Total -N = 3 (30)
BOD = 5 SS = 3 P = 7 TKN = 1 Total -N = 1-3 (4)
BOD = 10 SS = 5 P = 8 TKN = 1 Total - N = 3 (4)
BOD = 10-15 SS = 10-15 P = 1-2 TKN = 1 Total -N = 3 (18)
BOD = 15-20 SS = 15-20 P = 8 TKN = 1 Total -N = 3 (4)
BOD = 5 SS = 3 P = <1 TKN = 1 Total -N = 30 (6)
BOD = 10 SS = 5 P = 1 TKN = 1 Total -N = 30 (6)
BOD = 5 SS = 3 P = 8 TKN = 1 Total -N = 30 (2)
BOD = 10 SS = 5 P = 8 TKN = 1 Total -N = 30 (2)
BOD = 10-15 SS = 10-15 P = 8 TKN = 1 Total -N = 30 (2)
BOD = 15-25 SS = 15-20 P = 2 TKN = 1 Total -N = 30 (6)
BOD = 5 SS = 3 P = <1 (11)
BOD = 10 SS = 5 P = 1 (11)
BOD = 10 SS = 10 P = 1 (2)
BOD = 15-20 SS = 15-20 P = 2 (8)
BOD = 25 SS = 30 P = 8 (2)
A1
A2
A3
A4
A5
B1
B2
B3
C1
C2
C3
C4
C5
C6
C7
C8
F1
F2
G1
G2
G3
G4
D
E
H
I
J
K

DIAGRAM IV-1
COMBINING UNIT PROCESSES FOR
WASTEWATER TREATMENT SYSTEMS

SLUDGE HANDLING UNIT PROCESSES DESCRIPTION

L. Anaerobic Digestion

L-1 Sludge Influent: Generated from A-1+B-1, C-1 or C-6
L-2 Sludge Influent: Generated from A-1+C-4, or C-5, or C
A-4+B-3 or C-3, A-5+B-3 or C-3

M. Heat Treatment

M-1 Sludge Influent: Generated from A-1+B-1, C-1 or C-6
M-2 Sludge Influent: Generated from A-1+C-4 or C-5, or C
A-4+B-3 or C-3, A-5+B-3 or C-3

N. Air Drying

N-1 Sludge Influent: Effluent Sludge from L-1
N-2 Sludge Influent: Effluent Sludge from L-2

O. Dewatering

O-1 Sludge Influent: Generated from A-1+B-1, C-1 or C-6
O-2 Sludge Influent: Generated from A-1+C-4 or C-5, or C
A-4+B-3 or C-3, A-5+B-3 or C-3
O-3 Sludge Influent: Generated from A-2
O-4 Sludge Influent: Generated from A-3+B-2 or C-2
O-5 Sludge Influent: Effluent Sludge from L-1
O-6 Sludge Influent: Effluent Sludge from L-2
O-7 Sludge Influent: Generated from F-1 or F-2
O-8 Sludge Influent: Effluent Sludge from M-1
O-9 Sludge Influent: Effluent Sludge from M-2

P. Incineration

P-1 Influent Sludge: Effluent Sludge from O-1
P-2 Influent Sludge: Effluent Sludge from O-2
P-3 Influent Sludge: Effluent Sludge from O-3
P-4 Influent Sludge: Effluent Sludge from O-4
P-5* Influent Sludge: Effluent Sludge from O-7+O-1
P-6 Influent Sludge: Effluent Sludge from O-8
P-7 Influent Sludge: Effluent Sludge from O-9

Q. Recalcination (includes chemical storage & feeding)

Q-1 Sludge Influent: Effluent Sludge from O-3
Q-2 Sludge Influent: Effluent Sludge from O-4
Q-3 Sludge Influent: Effluent Sludge from O-7

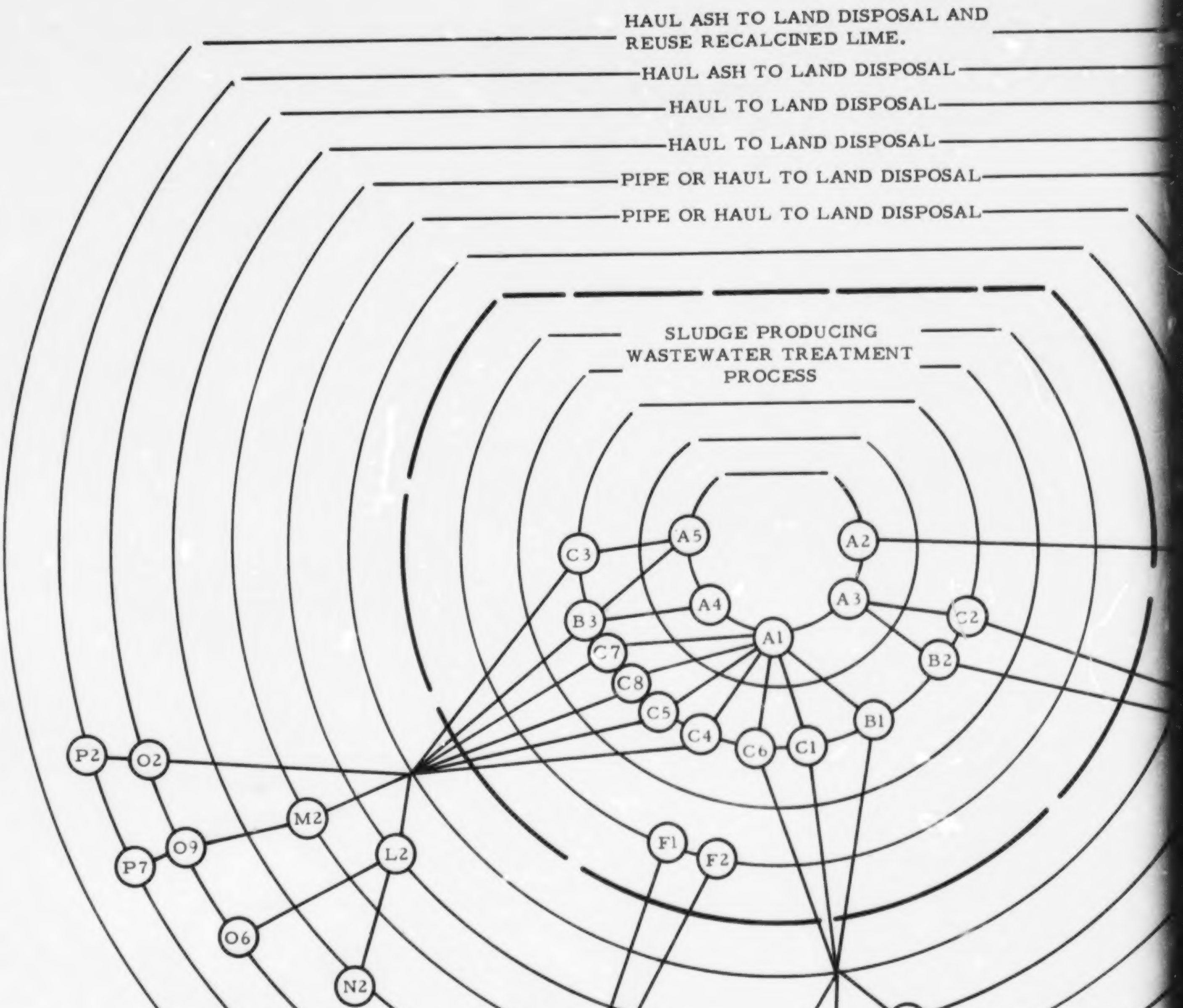
*Note - Use pathway from 0-1 to P-5 only when F-1 or F-2 is included in the complete system.

**Sludge leaving this process may be recalcined in part. If this is the case, the remainder may be either incinerated or hauled to disposal.

-7, or C-8,

-7, or C-8,

-7, or C-8,


HAUL ASH TO LAND DISPOSAL AND REUSE RECALCINED LIME.
HAUL ASH TO LAND DISPOSAL
HAUL TO LAND DISPOSAL
HAUL TO LAND DISPOSAL
PIPE OR HAUL TO LAND DISPOSAL
PIPE OR HAUL TO LAND DISPOSAL
SLUDGE PRODUCING WASTEWATER TREATMENT PROCESS
A5
A2
C3
A4
A3
B3
C2
A1
C7
B2
C8
C5
C4
C6
C1
B1
P2
O2
M2
O9
P7
L2
F1
F2
O6
N2
L1
M1
N1
**
O7
O1
*
O8
O5
Q3
P5
P1
P6

FC

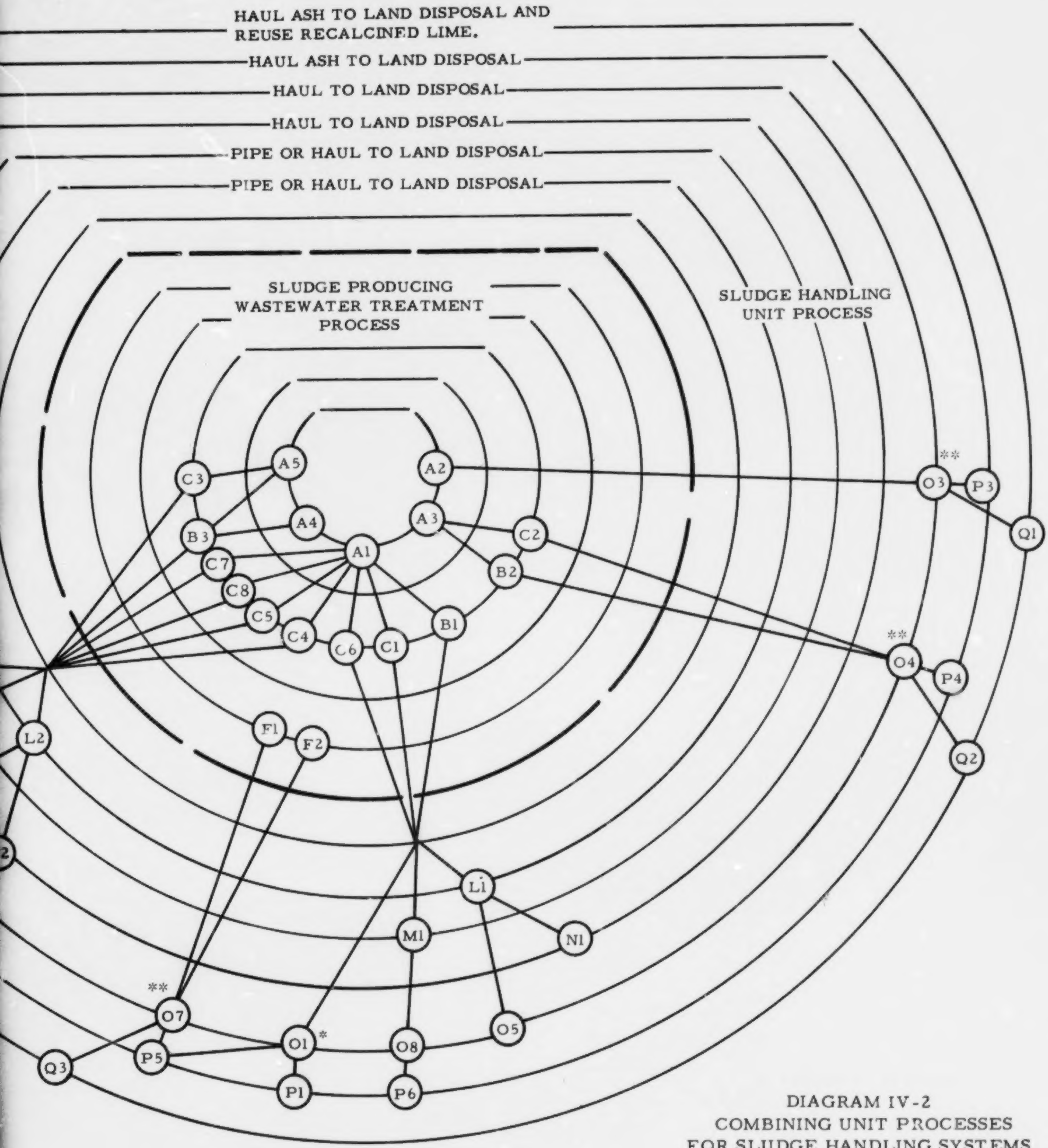

HAUL ASH TO LAND DISPOSAL AND REUSE RECALCINED LIME.
HAUL ASH TO LAND DISPOSAL
HAUL TO LAND DISPOSAL
HAUL TO LAND DISPOSAL
PIPE OR HAUL TO LAND DISPOSAL
PIPE OR HAUL TO LAND DISPOSAL
SLUDGE PRODUCING WASTEWATER TREATMENT PROCESS
SLUDGE HANDLING UNIT PROCESS
A5
A2
A4
A3
A1
C3
B3
C7
C8
C5
C4
C6
C1
B1
C2
B2
**
O3
P3
Q1
**
O4
P4
Q2
L2
F1
F2
L1
M1
N1
**
O7
P5
Q3
O1
*
O8
O5
P1
P6

DIAGRAM IV-2
COMBINING UNIT PROCESSES
FOR SLUDGE HANDLING SYSTEMS

Section V-Determining Cost-Effectiveness of Wastewater Treatment Systems

5.1 - Procedure for Use of Diagrams IV-1 and IV-2 and Comparing Alternative Systems Costs

Diagrams IV-1 and IV-2 can be used to easily find all logical unit process combinations to achieve a specific effluent quality, and to identify alternative sludge handling schemes. The general procedure for using the diagrams followed by three specific examples are presented below.

The following procedure is intended to simplify the use of the diagrams.

Step 1 Find the desired or required effluent quality located on the circumferential lines in the upper center portion of Diagram IV-1.

Step 2 Remembering that disinfection is usually the final unit process in any system, follow the circumferential line on which the desired effluent quality is located and stop at each unit process located on the line. These are the unit processes that could precede disinfection in a treatment system producing the desired effluent quality chosen. Also remember that preliminary treatment is the first process in any treatment system. If needed, raw wastewater pumping would follow preliminary treatment. Disinfection, preliminary treatment, and raw wastewater pumping have not been shown on the diagram because, being common to all or none of the treatment alternatives producing a given effluent, they exert no influence on the choice of one system over another. However, they must be included in the determinations of costs associated with each treatment system.

Step 3 Beginning with each of the processes on the circumference, follow the lined pathways toward the center of diagram noting each unit process comprising the system until reaching the unit process (A series) located nearest the center of the diagram. Include all possible pathways. Some pathways may branch, in which case more than one system would be obtained from a single beginning pathway. Make note of all possible systems that will give the required effluent. The total number of systems that should be found for each effluent quality are shown in parentheses beside the effluent qualities.

Step 4 Proceed to Diagram IV-2. For each system selected, certain processes generate waste sludges. Find (on Diagram IV-2) the sludge-producing unit process combinations which correspond to those systems chosen from Diagram IV-1.

Step 5 Follow the pathways to the sludge handling unit processes, making note of alternative sludge handling systems for each wastewater treatment system chosen. Ultimate disposal requirements are shown in the upper center portion of the diagram on the circumferential line associated with the last sludge handling unit process considered for each complete system. It should be noted in this diagram that some sludge handling systems will be common to several wastewater treatment unit process combinations. This is shown by converging pathways leading from the wastewater treatment unit processes to the sludge handling unit processes.

Step 6 After all unit processes associated with each complete wastewater treatment and sludge handling systems are listed, the total O & M. and amortized capital cost of each unit process can be found in the cost curves in Section III for plant sizes of 1-100 MGD. The total cost of each system can be found by adding all unit process total costs. Cost comparisons of alternative systems can then be made.

Although each system will generally meet the effluent quality listed on the same circumferential line of the last unit process in each system, some systems will produce slightly better effluent than others. Therefore the effluent values listed on Diagram IV-1 are shown as average values or narrow ranges of values. To determine the specific effluent value that can be achieved by specific processes or systems, the unit process flow diagrams in Section II should be referred to.

5.2 - Examples of Comparing Cost-Effectiveness of Complete Wastewater Treatment Systems

Three examples are presented to illustrate the use of the diagrams and cost curves to determine cost-effectiveness of various systems. The examples include wastewater treatment systems which must achieve the following effluent wastewater quality:

1. BOD ≤30 mg/l SS ≤ 35 mg/l, no P or N removal required
2. BOD ≤5 mg/l SS ≤3 mg/l, P ≤1 mg/l, no N removal required
3. BOD ≤5 mg/l SS ≤3 mg/l, P ≤1 mg/l, total N ≤3 mg/l

The examples assume the use of similar sludge handling systems where possible and recalcination of lime sludges. Costs are based on systems which must treat a 20 MGD influent wastewater flow.

Example 1 The step-by-step procedure to follow in the example is as follows:

Step 1 Locate (on Diagram IV-1) the effluent quality that meets the requirement. For this example, it is assumed preliminary treatment, pumping, and disinfection are needed. Processes which meet the BOD and SS criteria and include P removal need not be considered. The effluent quality on the second circumferential line from the center meets the criteria, and it is noted from the number in parentheses that two systems should be found which meet the required effluent quality.

Step 2 Proceed around the circumference stopping at C-1 and B-1. These processes would precede disinfection in each system.

Step 3 Following the lined pathways toward the center of the diagram, B-1 and C-1 both lead to A-1. Therefore, the two systems are A-1 + B-1 and A-1 + C-1. As noted from the process descriptions in the righthand column, these are conventional primary sedimentation + trickling filter and conventional primary sedimentation + activated sludge processes, respectively. Preliminary treatment AA, pumping AB, and disinfection R are common to both systems and consequently will not influence the choice of one system over the other. These costs, however, must be included in determining total liquid processing costs.

Step 4 Proceed to Diagram IV-2. Locate the two wastewater treatment systems A-1 + B-1 and A-1 + C-1. The presence of both unit processes in Diagram IV-2 comprising the two systems indicates that each unit process produces waste sludge.

Step 5 Follow the pathways from both systems to the outer section of the diagram. The two pathways converge indicating that the sludges generated by the two systems are of similar quantity and can be handled by common systems. Following the pathways further shows that four systems are capable of handling the sludges: L-1 + N-1 (anaerobic digestion + air drying), L-1 + O-5 (anaerobic digestion + dewatering), M-1 + O-8 + P-6 (heat treatment + dewatering + incineration), and O-1 + P-1 (dewatering + incineration).

Step 6 The total, amortized capital, and O & M costs for each unit process comprising each system can be taken from the cost curves in Section III and added to give total wastewater treatment costs and sludge handling costs. Total costs have been determined for each treatment system while the most cost-effective system has been broken down into O& M and amortized capital costs.

The example is shown in Table V-1. The costs of preliminary treatment AA, raw wastewater pumping AB, and disinfection R are common to both possible liquid systems. Adding these costs to A-1 + B-1 and A-1 + C-1, the table shows that system 1 costs 11.0¢/1000 gallons of influent and system 2 costs 9.3¢/1000 gallons. The least cost sludge handling system is L-1 + O-5, costing 2.4¢/1000 gallons. Therefore, the most cost-effective system would contain (AA + AB + A-1 + B-1 + R) + (L-1 + O-2) and cost 11.7 ¢/1000 gallons. Often, factors other than cost (such as those listed in Table III-2) might result in the selection of a less cost-effective system. Also, the cost of ultimate disposal of sludge or ash will vary depending upon sludge characteristics and quantities involved and can influence the selection of sludge handling and wastewater treatment alternatives.

Although the following two examples involve many more alternatives, the procedure remains the same.

TABLE V-1

EXAMPLE NO. 1

20 MGD Wastewater Treatment Plant Design for BOD and SS Removal Only

Effluent Quality				
	BOD (mg/l)	30	P (mg/l)	9
	SS (mg/l)	35	TN (mg/l)	30

(A) Wastewater Treatment Process Combinations and Liquid Process Cost (Total Annual Cost in Cents per 1000 gallons)

	1		2	
	Process	Cost	Process	Cost
	C-1	5.7	B-1	4.0
	A-1	1.3	A-1	1.3
	AA	0.7	AA	0.7
	AB	2.2	AB	2.2
	R	1.1	R	1.1
Subtotal		11.0		9.3

(B) Sludge Treatment Process Combinations (Both liquid process sludges will require same kind of treatment.)

Sludge Process Cost
(Total Annual Cost in Cents per 1000 gallons influent)

	1		2		3		4	
	Process	Cost	Process	Cost	Process	Cost	Process	Cost
	L-1	0.7	M-1	2.1	L-1	0.7	O-1	2.1
	N-1	2.4	O-8	1.4	O-5	1.7	P-1	2.6
	-	-	P-6	2.2	-	-	-	-
Subtotal		3.1		5.7		2.4		4.7

Use 2.4 cents/1000 gallons for sludge treatment process, but cost of sludge hauling and disposal on land must be included for complete cost-effective comparison.

(C) Total Annual Cost in Cents per 1000 gallons.
Process No. 1 11.0 + 2.4 = 13.4
Process No. 2 9.3 + 2.4 = 11.7

(D) O&M Cost and Amortized Capital Cost of the Most Cost-Effective System in Cents per 1000 gallons:

Most Cost-Effective System: (AA + AB + A-1 + B-1 + R) + (L-1 + O-5)
O&M Costs (from Cost Curves): (0.4 + 0.5 + 1.1 + 0.9) + (0.2 + 1.2)
Total O&M Cost: 3.4 + 1.4 = 4.8

Amortized Capital Cost: (0.3 + 1.7 + 0.8 + 2.9 + 0.2) + (0.5 + 0.6)
(From Cost Curves)

Total Amortized Capital Cost: 5.9 + 1.1 = 7.0

Example 2 The steps in this example are summarized below. The effluent which meets the requirements can be located on the sixth circumferential line from the center. Preliminary treatment and disinfection are included. Eleven possible systems exist, as noted from the number in parentheses. Starting from the unit processes located on that circumferential line, the eleven systems can be found which meet the desired effluent requirement by tracing the pathways into the center of the diagram. Proceeding to Diagram IV-2, the sludge producing unit processes associated with each system can be found, and corresponding sludge handling systems noted. For this example, only dewatering + incineration or recalcination where lime sludges are present are considered. Therefore, other possible alternative sludge handling systems are not considered for each total system. This example is presented in Table V-2. The unit process costs were found from the cost curves, totaled for each complete system, and recorded in Table V-2. The most cost-effective system combines (AA + A-3 + B-2 + D + E + R) + (O-4 + Q-2), or namely preliminary treatment, primary sedimentation + lime addition, trickling filter, filtration, activated carbon and disinfection followed by sludge dewatering + recalcination. The total cost of the system is 34.4¢/1000 gallons. However, 4 of the 10 other alternative systems were no more than 3¢/1000 gallons higher in total cost, as noted in Table V-2.

The two systems employing F-1 or F-2, tertiary lime treatment and recalcining of lime sludge, were significantly higher than other alternatives at a total cost of about 47¢/1000 gallons.

Example 3 The steps followed in this example are the same as for the first two examples, but involve selecting more alternative systems. The required effluent quality is found on the two outer circumferential lines. In this example, 19 + 11 (or 30) alternative systems are possible, as noted from the numbers in parentheses. All alternatives are easily found by locating a process on the circumference, and as in the other examples, tracing the pathways to the center. The 30 alternative systems are listed in Table V-3. Preliminary treatment and disinfection have been added as in Example 2. Similarly, only dewatering, incineration or recalcining where lime sludges are present are considered. Proceeding as in Example 2, the specific sludge handling processes for each system can be found. Those specific sludge handling processes associated with each system are also listed in Table V-3. The cost can then be found as in the previous examples. The costs are listed and totaled for the unit processes in each of the 30 systems. The most cost-effective system in this example is the same system found to be most cost-effective in Example 2 with the addition of ion-exchange, and costing a total of 41.9¢/1000 gallons. However, many of the other alternative systems are very close to the most cost-effective one.

It must be emphasized that certain constraints which might be present in particular cases could eliminate any of the combined systems from consideration.

TABLE V-2

EXAMPLE NO. 2

20 MGD Wastewater Treatment Plant Design for BOD, SS, and P Removal With Effluent Polishing

Effluent Quality:		
	BOD (mg/l)	5
	SS (mg/l)	3
	P (mg/l)	1
	TN (mg/l)	30

(A) Wastewater Treatment Process Combinations:

	1	2	3	4	5	6	7	8	9	10	11
	E	E	E	E	E	E	E	E	E	E	E
	D	D	D	D	D	D	D	D	D	D	D
	A-2	B-2	B-3	B-3	C-2	C-3	C-3	C-4	C-5	F-1	F-2
	AA	A-3	A-4	A-5	A-3	A-4	A-5	A-1	A-1	B-1	C-1
	R	AA	AA	AA	AA	AA	AA	AA	AA	A-1	A-1
		R	R	R	R	R	R	R	R	AA	AA
										R	R

Liquid Process Cost - (Total Annual Cost in Cents per 1000 gallons)

	1	2	3	4	5	6	7	8	9	10	11
	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
	2.9	3.3	3.5	3.5	4.9	4.8	4.8	9.5	9.5	2.6	2.6
	0.7	1.6	6.0	6.3	1.6	6.0	6.3	1.3	1.3	4.0	5.7
	1.1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.3	1.3
		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.7	0.7
										1.1	1.1
Subtotal	23.8	25.8	30.4	30.7	27.4	31.7	32.0	31.7	31.7	28.8	30.5

(B) Sludge Treatment Process Combinations Based on Only Dewatering, Incineration and Recalcination where applicable

	1	2	3	4	5	6	7	8	9	10	11
	0-3	0-4	0-2	0-2	0-4	0-2	0-2	0-2	0-2	0-1	0-1
	Q-1	Q-2	P-2	P-2	Q-2	P-2	P-2	P-2	P-2	0-7	0-7
										P-1	P-1
										Q-3	Q-3

Sludge Process Cost - (Total Annual Cost in Cents per 1000 gallons influent)

	1	2	3	4	5	6	7	8	9	10	11
	4.5	3.4	3.0	3.0	3.4	3.0	3.0	3.0	3.0	2.2	2.2
	8.5	5.2	5.6	3.6	5.2	3.6	3.6	3.6	3.6	3.7	3.7
										2.7	2.7
										8.8	8.8
Subtotal	13.0	8.6	6.6	6.6	8.6	6.6	6.6	6.6	6.6	17.4	17.4

Total Annual Cost in Cents per 1000 gallons

1	2	3	4	5	6	7	8	9	10	11
36.8	34.4	37.0	37.3	36.0	38.3	38.6	38.3	38.3	46.2	47.9

TABLE

EXAMPLE

20 MGD Wastewater Treatment Plant Design for BOD,

Effluent Quality		
	BOD (mg/l)	5
	SS (mg/l)	3
	P (mg/l)	1
	TN (mg/l)	4

(A) Wastewater Treatment Process Combinations:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	E D H G-4 C-7 A-1 AA R	E D H G-4 C-8 A-1 AA R	E D H G-3 A-3 AA R	E D H G-3 A-4 AA R	E D H G-3 A-5 AA R	E D H G-4 A-2 AA R	E D I A-2 AA R	E D I B-2 A-3 AA R	E D I B-3 A-4 AA R	E D I B-3 A-5 AA R	E D I C-2 A-3 AA R	E D I C-3 A-4 AA R	E D I C-3 A-5 AA R	E D I C-4 A-1 AA R	E D I C-5 A-1 AA R

Liquid Process Cost (Total Annual Cost in Cents per 1000 gallons)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	14.6 4.2 3.9 3.8 8.5 1.3 0.7 1.1	14.6 4.2 3.9 3.8 8.3 1.3 0.7 1.1	14.6 4.2 3.9 4.2 1.6 0.7 1.1	14.6 4.2 3.9 4.2 6.0 0.7 1.1	14.6 4.2 3.9 4.2 6.3 0.7 1.1	14.6 4.2 3.9 3.8 2.9 0.7 1.1	14.6 4.2 7.7 2.9 0.7 1.1	14.6 4.2 7.7 3.3 1.7 0.7 1.1	14.6 4.2 7.7 3.4 6.0 0.7 1.1	14.6 4.2 7.7 3.4 6.3 0.7 1.1	14.6 4.2 7.7 4.9 1.7 0.7 1.1	14.6 4.2 7.7 4.8 6.0 0.7 1.1	14.6 4.2 7.7 4.8 6.3 0.7 1.1	14.6 4.2 7.7 9.5 1.3 0.7 1.1	14.6 4.2 7.7 9.5 1.3 0.7 1.1
Subtotal	38.1	37.9	30.3	34.7	35.0	31.2	31.2	33.3	37.7	38.0	34.9	39.1	39.4	39.1	39.1

(B) Sludge Treatment Process Combinations Based On Only Dewatering, Incineration

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0-2 P-2	0-2 P-2	0-4 Q-2	0-2 P-2	0-2 P-2	0-3 Q-1	0-3 Q-1	0-4 Q-2	0-2 P-2	0-2 P-2	0-4 Q-2	0-2 P-2	0-2 P-2	0-2 P-2	0-2 P-2

Sludge Process Cost (Total Annual Cost in Cents per 1000 gallons influent)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	3.0 3.6	3.0 3.6	3.4 5.2	3.0 3.6	3.0 3.6	4.5 8.5	4.5 8.5	3.4 5.2	3.0 3.6	3.0 3.6	3.4 5.2	3.0 3.6	3.0 3.6	3.0 3.6	3.0 3.6
Subtotal	6.6	6.6	8.6	6.6	6.6	13.0	13.0	8.6	6.6	6.6	8.6	6.6	6.6	6.6	6.6

Total Annual Cost in Cents per 1000 gallons

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
44.7	44.5	38.9	41.3	41.6	44.2	44.2	41.9	44.3	44.6	43.5	45.7	46.0	45.7	45.7

a

TABLE V-3

EXAMPLE NO. 3

lant Design for BOD, SS, P and Nitrogen Removal with Effluent Polishing

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
3 4	E D I C-3 A-5 AA R	E D I C-4 A-1 AA R	E D I C-5 A-1 AA R	E D I F-1 B-1 A-1 AA R	E D I F-2 C-1 A-1 AA R	E D J A-2 AA R	E D J B-2 A-3 AA R	E D J B-3 A-4 AA R	E D J B-3 A-5 AA R	E D J C-2 A-3 AA R	E D J C-3 A-4 AA R	E D J C-3 A-5 AA R	E D J C-4 A-1 AA R	E D J C-5 A-1 AA R	E D J F-1 B-1 A-1 AA R	E D J F-2 C-1 A-1 AA R	E D K F-1 B-1 A-1 AA R	E D K F-2 C-1 A-1 AA R
ns)																		
.6 .2 .7 .8 .0 .7 .1	14.6 4.2 7.7 4.8 6.3 0.7 1.1	14.6 4.2 7.7 9.5 1.3 0.7 1.1	14.6 4.2 7.7 9.5 1.3 0.7 1.1	14.6 4.2 7.7 2.6 4.0 1.3 0.7 1.1	14.6 4.2 7.7 2.6 5.7 1.3 0.7 1.1	14.6 4.2 12.7 3.0 0.7 1.1	14.6 4.2 12.7 3.3 1.7 0.7 1.1	14.6 4.2 12.7 3.5 6.0 0.7 1.1	14.6 4.2 12.7 3.5 6.2 0.7 1.1	14.6 4.2 12.7 4.9 1.7 0.7 1.1	14.6 4.2 12.7 4.8 6.0 0.7 1.1	14.6 4.2 12.7 4.8 6.2 0.7 1.1	14.6 4.2 12.7 9.5 1.3 0.7 1.1	14.6 4.2 12.7 9.5 1.3 0.7 1.1	14.6 4.2 12.7 2.6 4.0 1.3 0.7 1.1	14.6 4.2 12.7 2.6 5.8 1.3 0.7 1.1	14.6 4.2 4.2 2.6 4.0 1.3 0.7 1.1	14.6 4.2 4.2 2.6 5.8 1.3 0.7 1.1
.1	39.4	39.1	39.1	36.2	37.9	36.3	38.3	42.8	43.0	39.8	44.1	44.3	44.1	44.1	41. 2	43.0	32.7	34.5
ring, Incineration and Recalcination Where Applicable:																		
2 -2	0-2 P-2	0-2 P-2	0-2 P-2	0-1 0-7 P-1 Q-3	0-1 0-7 P-1 Q-3	0-3 Q-1	0-4 Q-2	0-2 P-2	0-2 P-2	0-4 Q-2	0-2 P-2	0-2 P-2	0-2 P-2	0-2 P-2	0-1 0-7 P-1 Q-3	0-1 0-7 P-1 Q-3	0-1 0-7 P-1 Q-3	0-1 0-7 P-1 Q-3
ns influent)																		
.0 .6	3.0 3.6	3.0 3.6	3.0 3.6	2.2 3.7 2.7 8.9	2.2 3.7 2.7 8.9	4.5 8.5	3.4 5.2	3.0 3.6	3.0 3.6	3.4 5.2	3.0 3.6	3.0 3.6	3.0 3.6	3.0 3.6	2.2 3.7 2.7 8.9	2.2 3.7 2.7 8.9	2.2 3.7 2.7 8.9	2.2 3.7 2.7 8.9
.6	6.6	6.6	6.6	17.5	17.5	13.0	8.6	6.6	6.6	8.6	6.6	6.6	6.6	6.6	17.5	17.5	17.5	17.5
.7	46.0	45.7	45.7	53.7	55.4	49.3	46.9	49.4	49.6	48.5	50.7	57.9	50.7	50.7	58.7	60.5	50.2	52.0

APPENDICES

TABLE OF CONTENTS

Section		Page
	Introduction to Appendices	
Appendix A	Unit Process Description	A-1
Appendix B	Cost Formulae	B-1
Appendix C	Cost Effectiveness Analysis Guidelines	C-1

INTRODUCTION TO APPENDICES

These appendices were prepared to complement the revised edition of "A Guide to the Selection of Cost-Effective Wastewater Treatment Systems." This publication is not intended as a design manual but as an effective means for making cost comparisons. It allows decision makers or designers to update and revise the cost curves appearing in the aforementioned publication to obtain pertinent cost information on any of the following unit processes.

- Pump Stations
- Preliminary Treatment
- Primary Sedimentation
- Trickling Filtration
- Activated Sludge
- Gravity Filtration
- Granular Activated Carbon
- Two Stage Tertiary Lime Treatment
- Biological Nitrification
- Biological Denitrification
- Ion Exchange
- Breakpoint Chlorination
- Ammonia Stripping
- Disinfection

- Anaerobic Digestion
- Heat Treatment
- Air Drying
- Dewatering
- Incineration
- Recalcination

Appendix A concerns itself with a brief description of each unit process. Process objectives, major mechanical equipment and intended functions are discussed as are bases for capital and O&M costs.

Cost formulae for each unit process are presented in Appendix B. Each set of formulae consists of:

- A formula for amortized capital cost
- A formula for fixed operation and maintenance costs
- A formula for operation and maintenance costs which would be dependent on the quantity of wastewater treated

The formulae contain economic variables which may be changed as time and/or specific conditions warrant.

Appendix C is the Cost-Effectiveness Analysis Guidelines (40 CFR part 35)

A list of abbreviations and a bibliography follows Appendix C. The bibliography includes coding of each data source for one or more of the following areas of utilization:

- Treatment process characterization
- Process design parameters

- Sludge generation
- Treatment costs
- Sludge handling costs

Appendix A

UNIT PROCESS DESCRIPTIONS

This appendix contains a brief description for each unit process. Major topics covered include process objectives, average degrees of removal, major mechanical equipment and intended functions, and bases for capital and O&M costs. A directory of unit process descriptions follows.

Unit Process Description	Page
Preliminary Treatment	A-2
Raw Wastewater Pumping	A-7
Primary Sedimentation	A-9
Trickling Filtration	A-13
Activated Sludge	A-15
Gravity Filtration	A-18
Granular Activated Carbon	A-19
Two-Stage Tertiary Lime Treatment	A-21
Biological Nitrification	A-22
Biological Denitrification	A-24
Ion Exchange	A-25
Breakpoint Chlorination	A-26
Ammonia Stripping	A-27
Disinfection	A-28
Anaerobic Digestion	A-29
Heat Treatment	A-31
Air Drying	A-32
Dewatering	A-34
Incineration	A-36
Recalcination	A-37

AA. PRELIMINARY TREATMENT

The major function of preliminary treatment is to render the waste suitable for processing by subsequent treatment processes. This treatment includes the removal of large solids, such as rags and boards, which could damage pumps, and plug lines and inorganic grit which could cause operation and maintenance problems within the plant. Because measurement of the raw waste flow rate is normally made in the same structures as those in which preliminary treatment is achieved it is included in this section.

SCREENING

Large solids found in raw waste may be removed by either comminution or screening. In the former process the waste passes into a channel containing a low speed, rotating device equipped with cutting teeth which shreds the large solids without removing them from the wastewater. Comminution offers the advantage of being a simple single step, operation. Unfortunately, because of its continuous operation, communitor blades tend to dull quickly resulting in a deterioration in performance. Inadequately shredded materials will commonly build-up on moving equipment such as aerators, thus severely impeding their operation. This problem can be minimized, however, by proper maintenance.

Bar screens are more commonly used to remove large solids, especially in larger plants. These screens consist of parallel steel bars placed at an angle in a channel through which the waste flows. The clear openings between the bars vary from 3/4" to 2", depending upon the specific application. Solids collecting on the bars may be shredded at the point of collection or removed by automatic or manual rakes. In the latter case, the collected solids (i.e. screenings)may be either shredded and returned to the waste stream, incinerated, or buried in a sanitary landfill. Because such materials are highly putrescible, their prompt disposal is essential to good operation.

In evaluating the unit cost of preliminary treatment for this study, the use of bar screens was assumed with screenings being ground and returned to the plant influent.

FLOW MEASUREMENT

Several methods of flow measurement are available, depending on the specific application. The most common methods are:

- Venturi meters
- Magnetic flow meters
- Weirs
- Parshall flume (Venturi flume)

The first two devices listed above are used in closed pipes while the latter two are used in open channels. For measurement of flow in an open channel, a parshall flume is generally preferred because the loss in head is usually much less than the loss associated with a weir. Furthermore, a parshall flume when provided at the end of a channel with a parabolic cross section achieves a constant velocity in the channel, which is of a great advantage when constructed on the down stream side of a screen or a grit chamber. Thus the functions of flow measurement and velocity control can be achieved simultaneously.

A parshall flume operates on the basis of a restriction in the channel. The dimensions of each particular flume are such that the flow is a function of the depth of water in the flume. Thus, the rate of flow can be determined from a single upstream measurement of depth. Several devices for the measurement of depth are commercially available. Probably the most trouble free is the so called bubbler tube. This device consists of a vertical tube in the channel through which air is passed at a constant flow rate. As the depth of waste in the channel varies, the pressure required to force the air at the fixed rate to the bottom of the channel changes. By sensing this pressure, a signal is obtained which is proportional to flow. This may be either recorded locally or transmitted to the plant control room.

GRIT REMOVAL

Grit consists of high specific gravity solids, which enter the sewer system through infiltration and inflow during wet weather and from food preparation. Grit may consist of sand, gravel, cinders, eggshells, bone chips, seeds and large organic particles such as food wastes. It is not normally of concern as a pollutant but should be removed in order to reduce wear on moving mechanical equipment and to prevent deposition in pipe lines, channels, and conduits. Removal of grit also results in significant reduction in the cleaning frequency of a digester where grit will accumulate.

Grit removal may be achieved by any one of three methods. The first two methods are gravity and aerated grit chambers which provide short retention time sedimentation that allows rapidly settling grit to be removed, while lighter organic solids remain in suspension. Gravity grit chambers are generally horizontal flow chambers designed to provide nearly constant flow-through velocity. The velocity control may be provided by a series of narrow channels, but more common is some type of control section, such as a parshall flume, in the outlet channel. In the aerated grit chamber, an air diffuser located near the bottom of the chamber is used to induce a helical flow pattern. This provides a positive means of velocity control thus improving the grit removal efficiency. In both methods, the grit may be removed from the chamber either manually or by means of mechanical collectors, although the former method is limited to very small plants. Grit from these basins may be disposed of directly if suitable facilities are available. However, grit washing to remove organic materials is common practice. After washing, the grit is nonputrescible and may be landfilled or disposed of without creating undesirable nuisances.

A third method of grit removal is the cyclone separator. Although this method may be used at one of several locations in the pretreatment scheme, it is commonly used to degrit primary sludge. The grit is settled in a primary clarifier and pumped along with the primary sludge through a conical cyclone which uses centrifugal force to separate the grit in a highly efficient manner. Although this type of degritter results in increased wear on raw waste and primary sludge pumps, cyclone degritting is finding greater use because of over-all lower equipment maintenance cost.

For the purposes of this study, a gravity chamber with grit washing and separate disposal was assumed.

ITEMS INCLUDED IN COST ESTIMATES

The following items were included in preparation of the cost estimates for the various sized facilities:

Capital Cost

1. Flow channels and superstructures
2. Bar racks
3. Grinders (for screenings)
4. Grit chambers
5. Grit handling equipment
6. Parshall flume and flow recording equipment

Major O & M Costs

The quantity of grit collected and the degree of mechanization of the preliminary treatment system are the major factors affecting O&M costs. The cost of grit disposal has not been included but must be considered in estimating complete O&M costs.

AB. RAW WASTEWATER PUMPING

Raw wastewater pumping stations are normally designed to provide sufficient hydraulic head to permit gravity flow through the treatment plant. In general, it has been found to be more cost-effective to provide sufficient head in a single pump station than to provide multiple stations of lower heads within the plant. The exceptions to this are those situations where site topography prevents plant layout in such a manner that gravity flow can be readily achieved.

PUMP STATION DESIGN

Pump station design varies widely from plant to plant because of differences in capacity and head requirements. Generally, these pumping stations are of relatively low head (10'-40') and high capacity. Various types of pumps are in common use, but probably the most popular are the open impeller centrifugal pumps. Although these are relatively inefficient, they offer the advantage of being able to pass large solids, an essential feature of pumps used in this capacity.

An important consideration in the design of raw waste pumping stations is the diurnal variation of wastewater flow. Because of this variation, the pumping station must be capable of handling the peak instantaneous flow during the life of the plant. Further, sufficient standby capacity must be provided to insure that the maximum flow can be handled even though a portion of the pumping facility is out of service.

For this study, pump capacities were assigned for estimation of capital and O & M based on the 24 hour peak flow, while costs of the pumping station structure were based on ultimate pumping capacity. A typical value of 30' TDH (total dynamic head) was used to determine horsepower requirements and power costs.

24 hour Peak Flow MGD	Ultimate Pumping Capacity MGD
1	2
5	7.5
20	30
100	133

ITEMS INCLUDED IN COST ESTIMATES

The following items were included in preparation of the cost estimates.

Capital Cost

1. Pumps and standby units
2. Pumping station structure & auxiliary equipment
3. Electrical Control System
4. Normal earthwork

O&M Costs

Labor requirements will vary with degree of automation, type of pumping and auxiliary equipment installed. The cost of electric power will have a major effect on material and supply costs.

A. PRIMARY SEDIMENTATION

Gravity settling with or without the addition of chemicals is commonly used after preliminary treatment for the removal of suspended solids and BOD. Phosphorus removal may also be accomplished by the addition of chemical precipitants. For the purpose of this study, primary clarification has been divided into four categories depending on the type and mode of chemicals added to improve removal of suspended solids, BOD and phosphorus. Descriptions of each of these categories follows:

A1 CONVENTIONAL SEDIMENTATION

Settleable solids represent about 50% of the total suspended matter and 35% of the BOD contained in domestic sewage. Removal of this material from the waste by gravity sedimentation serves two important functions. First, the removal of BOD in the primary settling tanks reduces the loading on the subsequent treatment units. This has the effect of reducing both the capital and operating costs of such units. Secondly, the removal of the settleable solids ahead of biological treatment prevents their conversion to less readily dewaterable secondary sludge. This could have a major beneficial impact on the sizing and operation of sludge thickening and dewatering equipment.

The purpose of primary sedimentation tanks is to provide a quiescent condition to allow the solids in the waste to settle. These solids are then collected from the bottom of the tank and conveyed by scrapers to a trough or sump for removal as primary sludge.

The design basis of sedimentation tanks is based on the surface loading rate, expressed as the average rate of wastewater flow per square foot of tank surface area. Although the suitable loading rate depends on the characteristics of the suspended solids, an average overflow rate of 800 gallons/day/ft^2 has been found to accomplish complete removal of settleable solids from domestic wastewater. The required surface area of the primary sedimentation tanks in this study are based on this loading rate.

A2 TWO STAGE LIME ADDITION

In this modification, lime is rapidly mixed with the first-stage influent to obtain a minimum pH of 11. The water is stirred in the first-stage up-flow solids contact clarifier to encourage floc formation and precipitation. Following settling the water is discharged from the first-stage unit. Carbon dioxide is added to the water to reduce the pH in the second-stage to approximately 10, within range of the minimum calcium carbonate solubility. The water is again flocculated, settled and discharged. The pH of the process effluent is then neutralized with CO_2 or acid.

Solids produced in the first and second-stage units are mechanically collected, thickened and pumped to sludge treatment processes.

The increased efficiency of this process over conventional primary sedimentation resulting from flocculation of small suspended particles and precipitation of the oxygen demanding material combined with other physical chemical unit operations, sometimes eliminates the need for biological treatment. As much as 80% of the influent BOD, more than 90% of the suspended solids and approximately 90% of the phosphorus can be removed from the raw wastewater by this process. If a higher quality effluent is required this process can be followed by filtration and activated carbon to produce an effluent significantly lower in BOD and suspended solids than conventional secondary effluent.

Advantages of using lime over other chemical agents include

1) more easily dewaterable sludge solids,
2) almost complete destruction of bacteria and viruses,
3) precipitation of nearly all heavy metals, and
4) potential for recovery of much of the lime used.

A major disadvantage is the handling and disposal of large quantities of lime sludge.

A3 SINGLE STAGE LIME ADDITION

If a high degree of phosphorus removal is not required, and the wastewater composition is suitable, single-stage lime treatment may be satisfactory. This process is similar to the two stage system previously described. In this case, however, a pH of about 10 is used to promote maximum precipitation of calcium from the wastewater in one step. The up-flow solids contact clarifiers are essentially identical to those used in the two stage process.

Because of the lower pH used this modification requires significantly less lime and consequently produces less sludge than the two stage process. These advantages, however, are gained if lower removals of BOD, suspended solids and phosphorus are acceptable. The single stage process will normally produce reductions in BOD of about 60% with about 80% reductions in both suspended solids and phosphorus.

The advantages to the use of lime as a flocculant discussed in the previous sections apply equally well to the single stage processes. In some instances, however, recalcination may not be cost effective because of the reduced quantities of lime sludge produced.

A-4 and A-5 ALUM OR FERRIC CHLORIDE ADDITION

The similarities of unit processes A-4 and A-5 are sufficient to warrant their discussion together. Operationally, these processes are similar to single stage lime addition. Both the mode of chemical addition and the type of feed equipment required are essentially the same and the removals of BOD_5, suspended solids, and phosphorus are comparable.

The main advantages associated with the addition of either alum or ferric chloride in comparison to the use of lime lie in the fact that less sludge is produced, and mineral addition is effective in a pH range which is compatible with biological treatment systems. However, the sludge that is produced is more dilute and generally more difficult to dewater.

Both alum and ferric chloride are salts of strong acids and weak bases. Thus, when they are added to wastewater they form floc through reaction with the alkalinity present in the waste. If sufficient alkalinity is not present it must be added by dosing with small amounts of lime, or soda ash; the former being more frequently used.

Because both coagulants require the same type of equipment and achieve comparable results, the main factors involved in the selection of one over the other are the local cost of the materials and the ease with which either chemical can be handled at the specific plant site. Since wastewater composition and chemical costs vary considerably over the United States, the choice between these two must be made on a case by case basis.

ITEMS INCLUDED IN COST ESTIMATE

Capital Cost

Costs for clarifier sludge removal devices, piping, all pumps and sludge thickeners were included.

O & M Costs

For two stage lime treatment a dose rate of 400 mg/l (as CaO) was assumed while for single stage lime treatment 200 mg/l was used. Ferric chloride and alum dosages of 80 and 170 mg/l respectively were assumed. For all processes, the alkalinity of the wastewater was taken as 300 mg/l. For the ferric chloride addition, this necessitated a supplementary lime dose of 35 mg/l (as CaO).

Normal allowances for operation and maintenance of the equipment were included.

B. TRICKLING FILTRATION

A trickling filter consists of a circular bed packed with filter media, usually rock or a synthetic material. Primary effluent is uniformly applied over the media by means of a reaction driven rotary distributor. Microorganisms grow as a slime layer on the filter media and consume the organic material in the wastewater oxidizing a portion to carbon dioxide and water and converting the remainder to cell mass. Cellular material accumulates on the media until the combined effect of gravity and the flushing action of the percolating wastewater causes it to slough off. The treated wastewater containing this cellular material is collected in an underdrain system and conveyed to a secondary clarifier where the solids are removed as secondary sludge. A portion of the filter effluent may be returned as recycle before or after clarification.

Prior to the development of plastic media, trickling filters were largely limited to a depth of approximately 6 feet and BOD removals to about 75%. However with the development of lightweight media, bed depths greater than 20 feet are common. This reduces the required land area and increases the process efficiency.

The primary advantage of trickling filters is their simplicity of operation and dependability. Also, the relatively small amount of sludge produced is more easily dewatered then activated sludge.

The main disadvantages of trickling filters are their high land requirements, high capital cost and lower degree of process control. These, particularly in larger plants, outweigh the advantages noted above.

The subalternatives (B1, B2, B3) for trickling filters relate to the strength of the feed from different modifications of the primary treatment and not to changes in the trickling filter process itself.

ITEM INCLUDED IN COST ESTIMATES

Capital Costs

All costs for the filter structure, media, distribution system, collection system and secondary clarification system are included for six foot deep rock filters. Costs for raw waste pumping are not included since they would be covered, if required, by the raw waste pumping station. However, pumps and piping to provide for a 1:1 recycle ratio are included. Cost for thickening the secondary sludge by means of gravity thickeners are also included.

O & M Costs

Operating and maintenance costs include all direct labor and material required to operate and maintain the process in a proper manner.

C. ACTIVATED SLUDGE

Unlike a trickling filter, which is a fixed growth process activated sludge is a suspended growth process which biologically breaks down complex organic oxygen-demanding materials. A well-operated activated sludge system, preceded by primary sedimentation, is capable of removing in excess of 90 percent of the BOD and over 90 percent of the suspended solids in the influent wastewater.

The activated sludge system consists of aeration basins where primary effluent is continuously mixed with microorganisms. Air or oxygen required in the basin is introduced by means of diffusers or mechanical aerators. This aeration provides necessary dissolved oxygen to the microorganisms and sufficient mixing to maintain the cells in suspension. In a subsequent operation the activated sludge solids are separated from the treated wastewater. A portion of the microorganisms are returned to the aeration basins to be mixed with the incoming wastewater while the excess, which constitutes the waste sludge is sent to the sludge handling facilities.

The degree of treatment achieved in the activated sludge process is a function of several parameters. Most important of these are the mass of microorganisms returned per unit of biodegradable organic material (BOD) contained in the wastewater and the retention time of the aeration basins. In the design and operation of activated sludge systems these variables are combined into a single factor called the organic loading or food to microorganism ratio (F/M). This is defined as the amount of biodegradable organic material to a given amount of microorganisms per unit of time.

Activated sludge systems are classified as high rate, conventional, or extended aeration (low rate) based on the organic loading. In domestic wastewater treatment, extended aeration is not as frequently used because of the high biodegradability of the organic materials present in sewage. As a result, cost data for this process are not included. The table shown below gives the BOD and suspended solids removals which may be expected for conventional and high rate systems.

Process	Designation	Organic Loading (F/M)	BOD Removal	Suspended solids Removal
Conventional	C1-C3	0.25-1.0	90%	90%
High Rate	C6	1-3	70%	70%

Processes C1 through C3 differ only by the type of primary effluent received. Two stage lime treatment is not commonly employed prior to activated sludge treatment because of the high quality of effluent produced by lime treatment.

High rate activated sludge alone does not produce an effluent with BOD and suspended solids concentrations suitable for discharge into most surface waters in the United States. Thus, it is employed generally as a pretreatment process in a two stage activated sludge system, where the second stage is used for biological nitrification. In such an application it is desirable to carry a substantial amount of BOD (40-50 mg/l)into the nitrification step to develop sufficient biological solids in the nitrification reactor to aid in clarification of the nitrified effluent. Conversely, high rate activated sludge offers little additional treatment to the high quality effluent from primary treatment with single-stage lime, alum or ferric chloride addition.

Alum or ferric chloride are, however sometimes added directly to the aeration basins of either the conventional or high rate activated sludge systems after conventional primary sedimentation to precipitate phosphorus. This treatment will remove about 80% of the phosphorus. Cost data for these alternates are included under processes C4, C5, C7 and C8.

The main advantage to both conventional and high rate activated sludge systems is the lower initial cost of the systems particularly where a high quality effluent is required. This advantage is sometimes offset, in smaller plants, by the greater degree of operational complexity and higher operating costs of activated sludge systems.

ITEMS INCLUDED IN COST ESTIMATES

Capital Costs

Costs were developed using a F/M ratio of 0.5 for conventional systems and 1.5 for high rate systems. The aeration system and all other mechanical equipment and structures, (basins, buildings, etc.) were included. Secondary clarifiers were sized for an average overflow rate of 600 gal/day/ft^2 in all alternates. Provisions for sludges wastage and thickening were included. For those alternates involving chemical additions the dosage rates were the same as those specified for addition during primary sedimentation. Facilities for chemical storage and feed were included.

O & M Costs

Operating and maintenance costs include all direct labor required to operate and maintain the process in a proper manner. Where appropriate, all chemical costs were determined on the same bases as in primary treatment.

D. GRAVITY FILTRATION

All of the suspended matter in wastewater cannot be removed by gravity settling even after coagulation and flocculation. Thus, if a low effluent suspended solids concentration is required, filtration of the biological or two stage lime treatment effluent is generally necessary.

Filtration consists of passing the wastewater through a bed of porous material, separating the suspended matter from the water. As solids accumulate in the filter bed, it becomes necessary to backwash the bed by passing clean water at a high rate through the filter in a reverse direction to that of normal flow. The wash water, containing the suspended solids, is generally returned to the head of the plant and recycled through the primary clarifiers, although the wash water optionally can be returned to the other plant clarifiers when appropriate.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The capital cost of a filter installation is a function of the loading rate at which the wastewater may be applied. This loading is determined by characteristics of the filter media and the solids level of the water being applied. For this study a filtration rate of 4 gal/min/ft^2 was assumed, which is satisfactory for either a high quality biological effluent or effluent from two stage lime treatment. Facilities for storage of backwash water and all requisite pumps and piping were included.

O&M Costs

The O&M costs include all power and labor associated with filtration and backwash cycles.

E. GRANULAR ACTIVATED CARBON

At times it is necessary to achieve a greater degree of BOD removal than can be obtained by biological or two stage lime treatment combined with filtration. In such cases, it may be advantageous to use activated carbon adsorption when the residual BOD is in a soluble form. Treatment by this method consists of passage of the waste through a series of granular activated carbon columns. The soluble organics in the wastewater are adsorbed by the carbon, producing an effluent with less than 5 mg/l BOD.

With time, the carbon in the first column of the series becomes saturated with organic material. At this time the column is removed from service and the flow is directed to the next column in the series. The exhausted carbon is removed and the unit refilled with fresh material, after which it is placed back in service.

The exhausted carbon is reactivated by burning off organic material in a specially designed furnace. In each regeneration cycle, there is approximately 5 percent loss of carbon which has to be replenished with purchased material.

Activated carbon also aids in the removal of bacteria and viruses. Further, it reduces the levels of organo-metallic compounds, pesticides and other materials which may have not been removed in preceding treatment steps.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The major equipment included in estimating the capital cost is listed below.

1. Carbon columns including carbon beds
2. Regeneration furnace
3. Building
4. Backwash system

O&M Costs

O&M costs are broken down evenly between labor associated with carbon columns and furnace and material costs. Materials costs, in turn, are divided evenly between make-up carbon and fuel for the regeneration furnace.

F. TWO-STAGE TERTIARY LIME TREATMENT

This process is very similar in purpose to primary sedimentation. With two-stage lime addition, however, it follows, rather than precedes, biological treatment.

Reasons for placing lime treatment after biological treatment include:

- additional BOD removal
- phosphorous removal
- lime sludge produced is relatively uncontaminated with organic matter

The reader is directed to the discussion of Primary Sedimentation with Two-Stage Lime Addition, unit process A2. for a more complete description and other information pertaining to efficiency and cost.

G. BIOLOGICAL NITRIFICATION

Nitrogen in the form of ammonia and organic nitrogen compounds is present in medium strength domestic sewage at a concentration averaging 30 mg/l. High effluent ammonia concentrations are undesirable because ammonia can be toxic to fish, while both ammonia and organic nitrogen exert oxygen demand upon the receiving waters. Further since many forms of nitrogen including ammonia and organic nitrogen compounds serve as nutrients for aquatic growth, discharge of these compounds can contribute to eutrophication of receiving waters. Thus, in situations where eutrophication is of concern, complete removal of nitrogen may be required. In other applications, where oxygen resources of the stream are important, oxidation to the nitrate form may be adequate.

Conventional biological nitrification is similar to activated sludge treatment. The difference is that biological nitrification relies on a special group of autotrophic bacteria. These microbes derive energy by oxidizing ammonia to nitrite and thence to nitrate. Carbon for synthesis of cellular material is derived from carbon dioxide. Conventionally, biological nitrification is preceeded by treatment designed to achieve partial BOD removal. This reduces the size of the nitrification units but allows carry-over of some BOD to the nitrification reactors to stimulate the growth of heterotrophic organisms in the nitrification system which both removes the residual BOD and facilitates capture of the nitrifying bacteria in the clarifier.

Four different process options for biological nitrification are presented depending on the nature of the preceeding treatment steps. From a cost standpoint, the chief difference in these lies in the amount of air required in the reactor.

Air must be supplied not only for the biological conversion of ammonia to nitrate, but also for the removal of carbonaceous BOD. Therefore, systems with higher influent BOD concentrations will have greater air requirements. System G2 treats relatively low-BOD effluent from the trickling filter process and has the lowest air requirement. Processes Gl and G4 treat influents with moderate BOD concentrations and have intermediate air requirements. System G3 has the greatest air requirement of the four systems.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The major pieces of equipment included in the Capital Cost are listed below:

1. Aeration basins
2. Diffused air system
3. Final clarifiers
4. Return sludge pumps

O&M Costs

Labor costs for plant operation and maintenance of equipment are the major component of the O&M Costs.

H. BIOLOGICAL DENITRIFICATION

If nitrogen removal is desired in addition to oxidation, biological nitrification will be followed by denitrification. In this process the nitrified effluent is treated anoxically. In an anoxic environment, heterotrophic organisms convert the nitrates to nitrogen gas by utilizing nitrate as an oxidizing agent in the absence of dissolved oxygen. An outside carbon source, such as methanol, is generally required to provide food and energy to the denitrifiers.

Following denitrification, wastewater enters an aeration basin where air is blown into the liquid to release the nitrogen gas and to oxidize the last traces of methanol. Clarification follows and the denitrifying bacteria are returned to the anoxic reactor.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The major pieces of equipment considered in the capital cost are listed below:

1. Anaerobic reactors
2. Aeration basins
3. Diffused air system
4. Return sludge pumps
5. Final clarifiers
6. Methanol storage and feed system

O & M Costs

The greatest single O & M is that for methanol, which is assumed to be added at a rate of 3.5 lbs of methanol per lb of nitrate-nitrogen.

I. ION-EXCHANGE

An alternative to biological nitrification is the removal of ammonia by ion exchange. In this process, the wastewater is passed through a bed of clinoptilolite, a zeolite resin which selectively removes the ammonium ion. Once saturated with ammonium ions, the resin is regenerated with a lime slurry containing sodium chloride.

The waste produced by the regeneration is an alkaline, aqueous ammonia solution which requires final disposal. In this study, the waste is passed through a packed tower into which air or steam is injected to strip the ammonia gas. This ammonia gas is passed through an absorber material which has a high selectivity for ammonia. Disposal of the ammonia-bearing absorber material is not included.

Process efficiency is comparable to that of the conventional biological nitrification, with 0.5 to 1.0 mg/l ammonia in the effluent.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The major pieces of equipment included in the capital cost are listed below:

1. Clinoptilolite beds
2. Ammonia absorber
3. Regenerant storage
4. Stripping tower

Major O&M Costs

Material represents a significant portion of O&M costs. Most notable are:

1. Makeup clinoptilolite
2. Makeup regenerant
3. Ammonia absorbing material

The disposal of the ammonia-laden absorbing material is not included here but must be considered in estimating total O&M costs.

J. BREAKPOINT CHLORINATION

The addition of chlorine to ammonia laden water results in the production of chloramines. These chloramires may be further oxidized to nitrogen gas and nitrous oxides by adding additional chlorine to the "break-point". The gases formed are released from the water to the atmosphere.

Breakpoint chlorination offers a significant advantage in the removal of ammonia in that capital costs are very low. However, in larger plants, this is usually more than offset by the high cost of the chlorine required. Further, depression of the pH by the chlorine may require the addition of some lime for pH control prior to discharge.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The major pieces or equipment included in the capital cost are listed below.

1. Chlorine storage and feed system
2. Lime storage and feed system
3. Chlorine contact tank

O&M Costs

1. Chlorine
2. Lime

K. AMMONIA STRIPPING

Ammonia may be removed from wastewater by a physical stripping process. If the pH of a wastewater is raised to about 11 esentially all of the ammonium ion is converted to free ammonia. This gas may then be stripped by passing the waste through a packed tower having a counter current flow of air.

Stripping towers can be very effective in ammonia removal but their efficiency is highly dependent on air temperature. As the air temperature decreases, the ammonia removal efficiency drops significantly. This process, therefore, is not recommended in a cold climate. A major operational disadvantage of stripping is calcium carbonate scaling in the tower, which has been a persistent problem. Furthermore, the discharge of ammonia to the atmosphere can be a significant source of air pollution.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The major pieces of equipment included in the capital cost are listed below.

1. Ammonia stripping towers
2. Blower

O&M Costs

Costs are divided between power and labor.

R. DISINFECTION

Chlorination has been the most widely used method of disinfection of water and wastewater in the United States for many years. The efficiency of chlorine in the destruction of bacteria and viruses, combined with its relatively low cost, as compared with other disinfectants, has dictated its use in nearly all cases.

Because chlorine readily reacts with many substances found in wastewater, the effectiveness of chlorine as a disinfectant is dependent on a number of factors including pH, chlorine dosage, contact time, temperature, ammonia concentration, and the concentrations of other competing substances.

Since the determination of the bacterial levels in wastewater requires a minimum of 24 hours by standard techniques, such tests are of little use in controlling the process of chlorination. Thus, common practice has been to maintain a chlorine residual after a stipulated contact time Bactericidal observations of the effects at varying chlorine residuals are used to establish the required free chlorine residual and then the dosage of chlorine. Normally, a 15 minute contact time at maximum flow is provided with the chlorine dosage being automatically varied according to flow and residual.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

The chlorine storage and feed system plus contact basins are included in estimating the capital cost.

O & M Costs

The major component of O & M Costs is chlorine. For this effort, costs are based on a chlorine dose of 10 mg/l.

L. ANAEROBIC DIGESTION

Anaerobic digestion is a common method of sludge treatment used in domestic waste treatment plants. The process makes use of microorganisms to decompose the complex organic constituents in the sludges to methane, carbon dioxide and inert solid material. Methane has considerable fuel value and when removed from the digester may be used to heat buildings, produce steam, or to drive generators for the production of electricity. In addition to stabilizing degradable organic material, anaerobic digestion also results in a substantial decrease in the quantity of solids requiring further treatment and disposal.

Anaerobic digestion may be performed in either a single digester tank or in two tanks connected in series. In the latter case, the first tank, called the primary digester receives the raw sludge. The sludge is heated and continuously mixed to promote bacterial growth and good food - microorganisms contact. After a period of detention, the sludge is transferred to the second tank which is maintained in a quiescent state to promote separation of the solids into as thick a sludge as possible. Periodically, the water (supernatant) which has separated from the sludge in the secondary digester is decanted off and returned to the wastewater treatment operations. The solids are removed as a stabilized sludge from the bottom of the second stage digester and are pumped to subsequent sludge treatment operations. Single stage digestion does not achieve as high a degree of sludge stabilization or gas production as the two stage system. Single stage digesters are not as frequently used in modern plants and therefore, cost figures provided in this study are based on two stage digestion.

For the purposes of determing cost effectiveness, two unit processes have been presented. These differ only in the nature of the influent sludge. Process L1 treats sludges from conventional sedimentation and biological processes while unit process L2 receives sludges from wastewater processes where chemicals are used to assist sedimentation or to remove phosphorus. Because of this difference, unit process L1 will achieve a greater reduction in solids resulting in smaller dewatering systems.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

Capital costs include tanks, mixers, heating devices, controls and all other appurtances inherent in the process. Devices for the collection of gas from the digesters are included but no provision is made for the of utilization of this gas for power recovery.

O&M Costs

Labor represents the most significant O&M cost for anaerobic digestion. This process requires a high degree of operating control and supervision for peak efficiency. Various tests must be run periodically to monitor the digestion process and make appropriate adjustments. Proper maintenance requires the cleaning of digesters periodically and repairing equipment.

The cost of final sludge disposal has not been included here but must be considered for determination of total O&M costs.

M. HEAT TREATMENT

Heat treatment is a sludge dewatering process used as an alternative to anaerobic digestion. Raw sludge is heated with steam to approximately 360°F causing cellular material to rupture and release bound water, and water of hydration. After cooking at elevated pressure for about 30 minutes the sludge is cooled and discharged to a settling and thickening tank. Sludge is withdrawn from the thickener at 8 to 14% solids and pumped to a dewatering device.

The overflow from the thickener is a high-strength liquor typically containing 4500 mg/l BOD. This represents a considerable organic load if returned directly to the head of the plant. Pretreatment of the clarified liquor is sometimes practiced to reduce the BOD load to the system.

Heat treatment systems also are divided into two unit processes depending on the nature of the feed sludge. Unit process M-1 receives sludge from conventional sedimentation and biological treatment whereas M-2 is applicable for those sludges which contain chemical coagulants.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

Cost provisions were made for all necessary mechanical equipment including heat exchangers, reactors, thickeners and an additional aeration treatment system for thickener overflow.

O&M Costs

Operation and maintainance costs include all direct labor, steam generation, and a suitable allowance for replacement parts.

N. AIR DRYING

Air drying is a method of further concentrating a sludge after it has been stabilized by anerobic digestion. This process reduces the moisture content of the sludge to tacilitate handling and transport to an ultimate disposal site.

The sludge drying beds used in air drying are commonly constructed of a gravel bed covered by a layer of sand one half to one foot deep. The size of the beds is determined by the solids content of the influent sludge, the wetter the sludge the more land needed. The sludge beds can be designed as covered or open. Covered beds allow an all weather operation and thereby achieve a more efficient drying, thus a smaller land area is required. Conversely open beds, require relatively large areas and have a potential for causing problems that may be objectionable. Both evaporation, and seepage of moisture through the bed to an underdrain system are used to reduce the moisture content of the influent sludge. Natural evaporation is affected by surface winds, air temperature, and relative humidity. Seepage is affected by loading rates, influent sludge characteristics, and the nature of the filter media. The percolate is collected from the underdrains and returned to the head of the plant for treatment.

For purposes of this study, cost estimates were based on open beds. Operation and maintenance costs include bed cleaning but not ultimate disposal.

Air drying is divided into two unit processes , Nl and N2, according to the nature of the influent sludge. Combined chemical and biological sludge is treated in process N2, while process Nl treats only biological sludge.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

Costs are included for sand-gravel open air beds complete with underdrain system. Provision has also been made for collection of the percolate in a sump and pumping back to the head of the plant.

O&M Costs

Labor for sludge application, and removal is included. Appropriate provision has also been made for bed repair.

The cost of final sludge disposal has not been included here but must be considered in a determination of complete O & M costs.

Q. DEWATERING

The purpose of dewatering is to reduce the moisture content of raw or digested sludge. By increasing the solids content to approximately 30%, the cost of ultimate disposal is greatly reduced through reduction in both the weight and volume of material handled.

Vacuum filtration is probably the most popular method of mechanical dewatering in use and therefore is the method considered in this study. Depending on the nature of the sludge involved, dewatering may be preceeded by conditioning with chemicals, usually lime and ferric chloride, or organic polyelectrolytes.

The vacuum filter consists of a vat in which a cylindrical drum rotates. Sludge is fed to the vat where it forms a pool in the lower portion. The drum is partially covered by filter medium, which may be a cloth of natural or synthetic fibers, coil springs, or a wire mesh fabric. As the drum rotates slowly, part of its circumference is subject to an internal vacuum that draws sludge to the filter medium and permits the water to be drawn from the porous filter cake.

The solids are retained on the filter medium for removal as a cake during the drying cycle. The filtrate, in turn, passes into a compartment in the interior of the drum, where it is drawn to the filtrate receiver for return to the head of the plant.

Unit processes 01, 02, 05 and 06 refer to vacuum filtration of chemically conditioned sludges. These processes differ only in the character of the sludge received from the specific process. A filter cake of about 20% solids is normally achieved.

Unit processes 03, 04 and 07 deal with sludges produced by processes employing lime. These are separately considered because of the larger quantities of sludge to be handled. These sludges do not ordinairly require chemical conditioning and may be dewatered to 25-30% solids. Unit processes 08 and 09 cover dewatering of thermally conditioned sludges. No conditioning chemicals are required in these cases as well.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

Capital cost estimates include all mechanical equipment, pumps. piping, etc. An allowance is included for a structure to house the filter and controls. Where applicable, tanks for sludge conditioning are included.

O&M Costs

Costs include all labor and materials for normal operation and maintenance. Where applicable chemical costs for lime and ferric chloride are included at indicated application rates.

P. INCINERATION

Incineration is capable of considerable reduction in both weight and volume of dewatered sludges. Several types of commercial units are available; however the most common is the multiple hearth furnace used in this study. In this furnace, temperatures are maintained at slightly over 1400°F to insure complete combustion of the organic material. The sludge is burned with the aid of auxiliary fuel in the presence of excess air and after combustion produces an odorless and inert solid residue and combustion gases. These gases are sent to the afterburners and air scrubbers before being discharged to the atmosphere. The amount of sludge reduction varies directly with the volatile solids and moisture content of the feed sludge, but average 80 to 94%.

Due to the nature of various unit processes preceeding incineration, seven cases of incineration were evaluated in this study. Incineration has not been considered for sludges with low volatile solids contents, such as the digested sludges, since fuel requirements would be excessive.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

All necessary mechanical equipment, controls and other necessary equipment are included along with the devices required for air pollution control and ash handling. An allowance is made for a suitable structure for housing the incinerators.

O&M Costs

Maintenance of incinerators including refractory replacement, conveyers, ash handling equipment, control center, and enclosing structure are included. Also included are the costs for electric power, auxiliary fuel and ash removal. The cost of ash disposal has not been included here but must be considered in determining total O&M costs.

Q RECALCINATION

Lime recalcination consists of heating lime sludge in a furnace to temperatures of about 1850°F, driving off water and converting calcium carbonate to calcium oxide plus carbon dioxide. The carbon dioxide, and other stack gases, are passed through an afterburner and air scrubber. Carbon dioxide may be collected and used in other treatment processes. The recalcined lime, is conveyed to a storage hopper and mixed with makeup lime from a makeup lime storage bin.

Sludge character, and economic considerations determine what fraction of the influent sludge should be reclaimed. For example, the cost of new lime plus the cost of disposal of the lime sludge must be compared with the cost of equipment, fuel and operation of the recalcining facilities. With processes such as two stage lime treatment, the need for CO_2 is also a factor which should be considered.

Three cases under recalcination are presented. These are based on the variations in both quality and quantity of the influent lime sludge.

ITEMS INCLUDED IN COST ESTIMATES

Capital Cost

Allowances are included for all mechanical equipment, storage vessels and instrumentation.

O&M Costs

Estimates for fuel, labor and power are included. The quantity of lime recovered by recalcination is deducted from the quantity of lime used in the wastewater treatment processes.

APPENDIX B

COST EQUATIONS

Three formulae have been developed for each unit process. They are:

1. A formula for amortized capital cost
2. A formula for fixed operation and maintenance costs
3. A formula for flow-variable operation and maintenance cost

The formulae have been developed in such a manner that the following variables may be changed as time and/or specific conditions warrant:

Variable	Units	Symbol	Value Used to Determine Cost Curves(1)
Plant capacity	MGD	Q	1, 5, 20, 100
Amortization Period	years	n	20
Interest Rate(5)	%	i	5-5/8
Service and Interest Factor(2)	%	SIF	27
Labor Rate	$/man-hour	MHR	5
Land Cost	$/acre	ULC	2000
Wholesale Price Index Industrial Commodities(3), (5)	–	WPI	120
National Average Wastewater Treatment Plant Cost Index(4), (5)	–	STP	177.5

(1) Refers to "A Guide to the Selection of Cost-Effective Wastewater Treatment Systems."

(2) This includes allowance for engineering, contingencies, and interest during construction.

(3) As of February 1973.

(4) As of February 1973.

(5) For April 1975, WPI = 169.7 STP = 232.5 and i = 5 7/8% (Water Resources Council).

Two expressions used commonly deserve a brief explanation.

The term $\frac{1}{3650\ Q}$ appears in each of the three cost formulae and is used to convert dollars per year into cents per thousand gallons. The term $\frac{i\ (1+i)^n}{(1+i)^n - 1}$ appears in the formula for total amortized cost. It is known as the capital recovery factor and converts total capital investment in dollars to a yearly amortized cost in dollars per year based on interest rate i and amortization period n.

Several other terms appear commonly throughout each group of formulae. They are (1) base capital cost, BCC, (2) land requirements, LR, (3) base manhours, BMH, and (4) base material cost, BMC. Each term varies with flow for each unit process. Besides appearing individually in each group of unit process cost formulae, they are summarized in Table III-I appearing at the end of this section.

Note that the cost formulae have been developed using a least squares curve fitting method. The equations that appear in this section represent the best choice of equation over the range of input values. This is important to know when using the cost formulae for very small values of Q. In these situations, some equations yield negative values. This is true, for instance, with the formula for the land requirement for the ion-exchange process:

$$LR = -0.17 + 0.021\ Q$$

For values of Q less than 8, the value of LR is less than 0.

The reader should realize that this occurs only due to poor curve fit at low values of Q. In such occurrences, a zero value should be substituted for any negative numbers thus obtained. Under no circumstances should a negative value be used.

The following formulae apply to any of the unit processes for which flow sheets were developed in Section II.

Total Amortized Capital Cost, ¢/ 1000 Gal. =

$$\left[(\mathrm{BCC})\left(\frac{\mathrm{STP}}{177.5}\right) + (\mathrm{LR})(\mathrm{ULC})\right]\left[\frac{100 + \mathrm{SIF}}{100}\right]\left[\frac{1}{3650Q}\right]\ \mathrm{CRF}^{(1)}$$

where

BCC, Base Capital Cost, $. = Refer to Table B-1
LR, Land Requirement, Acres = Refer to Table B-1

Fixed Operation and Maintenance Costs, ¢/1000 Gal. =

$$(\mathrm{BMH})(\mathrm{MHR})\left(\frac{1}{3650Q}\right),$$

where

BMH, Base Man-hour Requirement, Man-hours/Yr. = Refer to Table B-1

Variable Operation and Maintenance Costs, ¢/1000 Gal. =

$$(\mathrm{BMC})\left(\frac{\mathrm{WPI}}{120}\right)\left(\frac{1}{3650Q}\right),$$

where

BMC, Base Material Costs, $/Yr. = Refer to Table B-1

(1) CRF (Capital recovery factor) $= \frac{i(1+i)^n}{(1+i) - 1}$

Table B-1

FLOW VARIABLE COST ELEMENTS

Unit Process	Base Capital Cost (BCC)	Land Requirement(LR)	Base Manhours (BMH)	Base Materials Cost (BMC)
AA	$32331\ Q^{0.61}$	0	1379.2 + 143.1 Q	860.6 + 247.7 Q
AB	$163612\ Q^{0.62}$	0	738.2 + 39.9 Q	$\frac{Q}{0.000885 + 0.000023\ Q}$
A1	139753 + 17341.2 Q	0.23 + 0.088 Q	$1852.8\ Q^{0.42}$	$1158.4\ Q^{0.62}$
A2	307785 + 33538.6 Q	0.16 + 0.18 Q	$4259.3\ Q^{0.41}$	$2956.2\ Q^{0.66}$
A3	198801 + 19934.9 Q	0.68 + 0.11 Q	3260.8 + 161.1 Q	$1694.4\ Q^{0.65}$
A4	241226 + 33921.4 Q	0.26 + 0.16 Q	$2783.4\ Q^{0.47}$	$\frac{Q}{0.0000662 + 0.00000036\ Q}$
A5	269563 + 33561.5 Q	0.26 + 0.16 Q	$2805.5\ Q^{0.43}$	2982.5 + 14255.3 Q
B1	232882 + 84335 Q	$1.20\ Q^{0.81}$	$2558.4\ Q^{0.51}$	4097.3 + 902.0 Q
B2	241083 + 63200.5 Q	$0.79\ Q^{0.84}$	$2500.8\ Q^{0.48}$	3525.8 + 895.8 Q
B3	241083 + 63200.5 Q	$0.79\ Q^{0.84}$	$2500.8\ Q^{0.48}$	3525.8 + 895.8 Q
C1	359744 + 84786.7 Q	$0.76\ Q^{0.80}$	$4574.8\ Q^{0.45}$	$10499.7\ Q^{0.73}$
C2	349156 + 67047.4 Q	0.46 + 0.32 Q	6228.4 + 303.5 Q	$10233.9\ Q^{0.73}$
C3	349156 + 67047.4 Q	0.46 + 0.32 Q	6228.4 + 303.5 Q	$10233.9\ Q^{0.73}$
C4	395978 + 89419.7 Q	$0.78\ Q^{0.81}$	$4834.7\ Q^{0.47}$	184641.1 + 15301.8 Q
C5	411240 + 89839.2 Q	$0.78\ Q^{0.81}$	$5093.2\ Q^{0.47}$	18720.2 + 14714.7 Q
C6	348852 + 53752.3 Q	$0.50\ Q^{0.84}$	$4292.9\ Q^{0.44}$	$10336.4\ Q^{0.73}$
C7	395350 + 59528.6 Q	$0.78\ Q^{0.81}$	6959.8 + 360.6 Q	18466.2 + 15301.5 Q
C8	413737 + 59627.4 Q	$0.50\ Q^{0.84}$	$4898.9\ Q^{0.45}$	20047.7 + 14697.0 Q
D	$231495.0\ Q^{0.66}$	0.024 + 0.028 Q	$\frac{Q}{0.00068 + 0.00058\ Q}$	$16491.9\ Q^{0.68}$
E	629840 + 90719.4 Q	0.024 + 0.028 Q	1600.0 Q	$\frac{Q}{0.00011245 + 0.00000014\ Q}$
F1	327175 + 33438.9 Q	0.16 + 0.18 Q	$2981.1\ Q^{0.46}$	$2027.6\ Q^{0.65}$
F2	327175.0 + 33438.9 Q	0.16 + 0.18 Q	$2981.1\ Q^{0.46}$	$2027.6\ Q^{0.65}$
G1	210055 + 59204.6 Q	$0.50\ Q^{0.84}$	3503.5 + 192.4 Q	$8756.5\ Q^{0.75}$
G2	203714 + 56924.2 Q	$0.50\ Q^{0.84}$	3360.1 + 183.9 Q	$8756.5\ Q^{0.75}$
G3	209599 + 65633.4 Q	0.44 + 0.24 Q	3820.6 + 226.0 Q	$8756.5\ Q^{0.75}$
G4	210055 + 59204.6 Q	$0.50\ Q^{0.84}$	3503.5 + 192.4 Q	$8756.5\ Q^{0.75}$
H	155767 + 37290.7 Q	0.49 + 0.16 Q	$2031.1\ Q^{0.42}$	-3559.4 + 8110.1 Q
I	$163270\ Q^{0.88}$	-0.17 + 0.021 Q	$3746.2\ Q^{0.72}$	$15161.5\ Q^{0.86}$

Table B-1 (Continued)

Unit Process	Base Capital Cost (BCC)	Land Requirement (LR)	Base Manhours (BMH)	Base Materials Cost (BMC)
J	$136587\ Q^{0.52}$	$-0.081 + 0.047\ Q$	$3043.2\ Q^{0.41}$	$2399.3 + 39947.7\ Q$
K	$93029.1\ Q^{0.89}$	$-0.016 + 0.04\ Q$	$3385.6 + 660.2\ Q$	$2103.0 + 3490.0\ Q$
R	$62270.5 + 5127.1\ Q$	$0.21 + 0.018\ Q$	$462.6\ Q^{0.60}$	$-1748.7 + 2739.3\ Q$
L1	$111168 + 23450.4\ Q$	$0.40 + 0.09\ Q$	$923.39 + 108.1\ Q$	$1384.2 + 152.4\ Q$
L2	$103721 + 21188.3\ Q$	$0.32 + 0.09\ Q$	$896.1 + 94.2\ Q$	$1441.8 + 140.7\ Q$
M1	$92686.9 + 12701.3\ Q$	0	$2246.7 + 313.9\ Q$	$2810.5 + 1025.8\ Q$
M2	$101672\ Q^{0.55}$	0	$2039.8 + 314.7\ Q$	$2148.8 + 1025.0\ Q$
N1	$-14885.6 + 57978.60$	$1.5 + 1.9\ Q$	$\frac{Q}{0.000518 + 0.00001161\ Q}$	$5.4 + 822.7\ Q$
N2	$\frac{Q}{0.00000971 + 0.000000101\ Q}$	$\frac{Q}{0.287 + 0.0000972\ Q}$	$\frac{Q}{0.000490 + 0.000002\ Q}$	$\frac{Q}{0.001156 - 0.0000136\ Q}$
O1	$153201 + 27538.5\ Q$	$-0.026 + 0.021\ Q$	$2264.1 + 488.9\ Q$	$6231.8\ Q^{0.86}$
O2	$123189\ Q^{0.71}$	$-0.026 + 0.016\ Q$	$2510.8 + 514.9\ Q$	$8059.1 + 3513.6\ Q$
O3	$194601.0 + 45218.2\ Q$	$-0.046 + 0.021\ Q$	$2624.6\ Q^{0.78}$	$8681.0\ Q^{0.70}$
O4	$173784 + 37399.2\ Q$	$-0.043 + 0.018\ Q$	$2391.8 + 920.04\ Q$	$6875.3\ Q^{0.73}$
O5	$140189 + 22599.2\ Q$	$-0.04 + 0.018\ Q$	$1899.5 + 385.5\ Q$	$6061.6\ Q^{0.86}$
O6	$152608 + 22520.1\ Q$	$-0.026 + 0.017\ Q$	$2339.4 + 405.2\ Q$	$5978.1\ Q^{0.88}$
O7	$168827 + 31955.5\ Q$	$-0.043 + 0.016\ Q$	$3352.5 + 880.9\ Q$	$7524.1\ Q^{0.71}$
O8	$127953 + 13386.5\ Q$	$-0.023 + 0.015\ Q$	$1916.3 + 482.0\ Q$	$4058.8\ Q^{0.73}$
O9	$123931 + 18524.6\ Q$	$-0.026 + 0.016\ Q$	$1966.1 + 507.7\ Q$	$4481.9\ Q^{0.71}$
P1	$378837\ Q^{0.54}$	$-0.084 + 0.015\ Q$	$1280.6 + 509.2\ Q$	$7136.4 + 728.8\ Q$
P2	$386161\ Q^{0.57}$	$-0.084 + 0.012\ Q$	$1521.8 + 504.7\ Q$	$9938.7 + 933.7\ Q$
P3	$631877 + 67043.6\ Q$	$-0.084 + 0.011\ Q$	$1281.8 + 735.4\ Q$	$20391.1 + 1974.8\ Q$
P4	$410798\ Q^{0.58}$	0	$1286.8 + 609.1\ Q$	$13163.9 + 1214.7\ Q$
P5	$286299\ Q^{0.53}$	$-0.084 + 0.013\ Q$	$1519.3 + 291.4\ Q$	$7926.8 + 549.8\ Q$
P6	$390808\ Q^{0.54}$	$-0.084 + 0.015\ Q$	$1433.9 + 492.1\ Q$	$12703.3 + 1267.2\ Q$
P7	$634606 + 65598.6\ Q$	$-0.084 + 0.012\ Q$	$1464.1 + 697.8\ Q$	$8507.3 + 891.9\ Q$
Q1	$422409\ Q^{0.58}$	$-0.17 + 0.021\ Q$	$3048.8 + 550.9\ Q$	$4264.7 + 14698.8\ Q$
Q2	$331428\ Q^{0.54}$	$-0.17 + 0.021\ Q$	$1770.4 + 356.9\ Q$	$3267.5 + 7913.7\ Q$
Q3	$534671\ Q^{0.59}$	$-0.17 + 0.021\ Q$	$1904.0 + 911.1\ Q$	$-262.8 + 12458.3\ Q$

APPENDIX C COST EFFECTIVENESS ANALYSIS GUIDELINES

federal register

Title 40—Protection of the Environment

CHAPTER I—ENVIRONMENTAL PROTECTION AGENCY

SUBCHAPTER D—GRANTS

PART 35—STATE AND LOCAL ASSISTANCE

Appendix A—Cost-Effectiveness Analysis

On July 3, 1973, notice was published in the FEDERAL REGISTER that the Environmental Protection Agency was proposing guidelines on cost-effectiveness analysis pursuant to section 212(2) (c) of the Federal Water Pollution Act Amendments of 1972 (the Act) to be published as appendix A to 40 CFR part 35.

Written comments on the proposed rulemaking were invited and received from interested parties. The Environmental Protection Agency has carefully considered all comments received. No changes were made in the guidelines as earlier proposed. All written comments are on file with the agency.

Effective date.—These regulations shall become effective October 10, 1973.

Dated September 4, 1973.

JOHN QUARLES,
Acting Administrator.

APPENDIX A

COST EFFECTIVENESS ANALYSIS GUIDELINES

a. *Purpose.*—These guidelines provide a basic methodology for determining the most cost-effective waste treatment management system or the most cost-effective component part of any waste treatment management system.

b. *Authority.*—The guidelines contained herein are provided pursuant to section 212 (2)(C) of the Federal Water Pollution Control Act Amendments of 1972 (the Act).

c. *Applicability.*—These guidelines apply to the development of plans for and the selection of component parts of a waste treatment management system for which a Federal grant is awarded under 40 CFR, Part 35.

d. *Definitions.*—Definitions of terms used in these guidelines are as follows:

(1) *Waste treatment management system.*—A system used to restore the integrity of the Nation's waters. Waste treatment management system is used synonymously with "treatment works" as defined in 40 CFR, Part 35.905–15.

(2) *Cost-effectiveness analysis.*—An analysis performed to determine which waste treatment management system or component part thereof will result in the minimum total resources costs over time to meet the Federal, State or local requirements.

(3) *Planning period.*—The period over which a waste treatment management system is evaluated for cost-effectiveness. The planning period commences with the initial operation of the system.

(4) *Service life.*—The period of time during which a component of a waste treatment management system will be capable of performing a function.

(5) *Useful life.*—The period of time during which a component of a waste treatment management system will be required to perform a function which is necessary to the system's operation.

e. *Identification, selection and screening of alternatives*—(1) *Identification of alternatives.*—All feasible alternative waste management systems shall be initially identified. These alternatives should include systems discharging to receiving waters, systems using land or subsurface disposal techniques, and systems employing the reuse of wastewater. In identifying alternatives, the possibility of staged development of the system shall be considered.

(2) *Screening of alternatives.*—The identified alternatives shall be systematically screened to define those capable of meeting the applicable Federal, State, and local criteria.

(3) *Selection of alternatives.*—The screened alternatives shall be initially analyzed to determine which systems have cost-effective potential and which should be fully evaluated according to the cost-effectiveness analysis procedures established in these guidelines.

(4) *Extent of effort.*—The extent of effort and the level of sophistication used in the cost-effectiveness analysis should reflect the size and importance of the project.

f. *Cost-Effective analysis procedures*—(1) *Method of Analysis.*—The resources costs shall be evaluated through the use of opportunity costs. For those resources that can be expressed in monetary terms, the interest (discount) rate established in section (f)(5) will be used. Monetary costs shall be calculated in terms of present worth values or equivalent annual values over the planning period as defined in section (f)(2). Nonmonetary factors (e.g., social and environmental) shall be accounted for descriptively in the analysis in order to determine their significance and impact.

The most cost-effective alternative shall be the waste treatment management system determined from the analysis to have the lowest present worth and/or equivalent annual value without overriding adverse nonmonetary costs and to realize at least identical minimum benefits in terms of applicable Federal, State, and local standards for effluent quality, water quality, water reuse and/or land and subsurface disposal.

(2) *Planning period.*—The planning period for the cost-effectiveness analysis shall be 20 years.

(3) *Elements of cost.*—The costs to be considered shall include the total values of the resources attributable to the waste treatment management system or to one of its component parts. To determine these values, all monies necessary for capital construction costs and operation and maintenance costs shall be identified.

Capital construction costs used in a cost-effectiveness analysis shall include all contractors' costs of construction including overhead and profit; costs of land, relocation, and right-of-way and easement acquisition; design engineering, field exploration, and engineering services during construction; administrative and legal services including costs of bond sales; startup costs such as operator training; and interest during construction. Contingency allowances consistent with the level of complexity and detail of the cost estimates shall be included.

Annual costs for operation and maintenance (including routine replacement of equipment and equipment parts) shall be included in the cost-effectiveness analysis. These costs shall be adequate to ensure effective and dependable operation during the planning period for the system. Annual costs shall be divided between fixed annual costs and costs which would be dependent on the annual quantity of wastewater collected and treated.

(4) *Prices.*—The various components of cost shall be calculated on the basis of market prices prevailing at the time of the cost-effectiveness analysis. Inflation of wages and prices shall not be considered in the analysis. The implied assumption is that all prices involved will tend to change over time by approximately the same percentage. Thus, the results of the cost effectiveness analysis will not be affected by changes in the general level of prices.

Exceptions to the foregoing can be made if their is justification for expecting significant changes in the relative prices of certain items during the planning period. If such cases are identified, the expected change in these prices should be made to reflect their future relative deviation from the general price level.

(5) *Interest (discount) rate.*—A rate of 7 percent per year will be used for the cost-effectiveness analysis until the promulgation of the Water Resources Council's "Proposed Principles and Standards for Planning Water and Related Land Resources." After promulgation of the above regulation, the rate established for water resource projects shall be used for the cost-effectiveness analysis.

(6) *Interest during construction.*—In cases where capital expenditures can be expected to be fairly uniform during the construction period, interest during construction may be calculated as $I \times \frac{1}{2} P \times C$ where:

I = the interest (discount) rate in Section f(5).
P = the construction period in years.
C = the total capital expenditures.

In cases when expenditures will not be uniform, or when the construction period will be greater than three years, interest during construction shall be calculated on a year-by-year basis.

(7) *Service life.*—The service life of treatment works for a cost-effectiveness analysis shall be as follows:

Land	Permanent
Structures (includes plant buildings, concrete process tankage, basins, etc.; sewage collection and conveyance pipelines; lift station structures; tunnels; outfalls)	30-50 years
Process equipment (includes major process equipment such as clarifier mechanism, vacuum filters, etc.; steel process tankage and chemical storage facilities; electrical generating facilities on standby service only).	15-30 years
Auxiliary equipment (includes instruments and control facilities; sewage pumps and electric motors; mechanical equipment such as compressors, aeration systems, centrifuges, chlorinators, etc.; electrical generating facilities on regular service).	10-15 years

Other service life periods will be acceptable when sufficient justification can be provided.

Where a system or a component is for interim service and the anticipated useful life is less than the service life, the useful life shall be substituted for the service life of the facility in the analysis.

(8) *Salvage value.*—Land for treatment works, including land used as part of the treatment process or for ultimate disposal of residues, shall be assumed to have a salvage value at the end of the planning period equal to its prevailing market value at the time of the analysis. Right-of-way easements shall be considered to have a salvage value not greater than the prevailing market value at the time of the analysis.

Structures will be assumed to have a salvage value if there is a use for such structures at the end of the planning period. In this case, salvage value shall be estimated using straightline depreciation during the service life of the treatment works.

For phased additions of process equipment and auxiliary equipment, salvage value at the end of the planning period may be estimated under the same conditions and on the same basis as described above for structures.

When the anticipated useful life of a facility is less than 20 years (for analysis of interim facilities), salvage value can be claimed for equipment where it can be clearly demonstrated that a specific market or reuse opportunity will exist.

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ABBREVIATIONS AND BIBLIOGRAPHY

ABBREVIATIONS

BCC	base capital costs, $
BMC	base material costs, $/yr
BOD	biochemical oxygen demand
BTU	British thermal units
BTU/cu. ft.	British thermal units per cubic foot
$CaCl_2$	Calcium chloride
CaO	Calcium oxide
$Ca(OH)_2$	Calcium hydroxide
cu. ft.	cubic foot
cf/lb	cubic feet per pound
cfm	cubic feet per minute
cfs	cubic feet per second
CO_2	carbon dioxide
COD	chemical oxygen demand
$^{\circ}F$	degree Fahrenheit
$FeCl_3$	Ferric Chloride
ft	foot
ft^2	square foot
gal	gallons
gpd	gallons per day
gpd/ft^2	gallons per day per square foot
gph	gallons per hour
gpm	gallons per minute
hr	hour
i	interest rate, %
l	liters
LR	land requirement, acres
lb	pounds
mg	milligrams
mg/l	milligrams per liter
MGD	million gallons per day
MGD/AC	million gallons per day per acre
MHR	manhour rate, $/manhour
ml	milliliter
MLSS	mixed liquor suspended solids
n	amortization period, years
NaCl	sodium chloride - common salt
NH_3	ammonia
NH_3-N	ammonia-nitrogen
O_2	Oxygen
P	Phosphorus
Ⓟ	sewage pump
pH	hydrogen ion concentration
ppm	parts per million (1 ppm equivalent to mg/l)
Q	flow rate, MGD

RAS	returned activacted sludge
RS	returned sludge
SIF	engineering, contingencies, and interest during construction; % of construction
SP	sludge pump
SS	suspended solids
STP	national average wastewater treatment plant cost index
TKN	total kjeldahl nitrogen
T-N	total nitrogen
ULC	unit land cost, $/acre
VP	vacuum pump
WPI	wholesale price index for industrial commodities

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Process Design Parameters	2
Sludge Generation	3
Treatment Costs	4
Sludge Handling Costs	5

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